From Stellar Spectra To Chemical Abundance Analysis

INAF - Osservatorio Astronomico di Trieste

Kutluay YÜCE

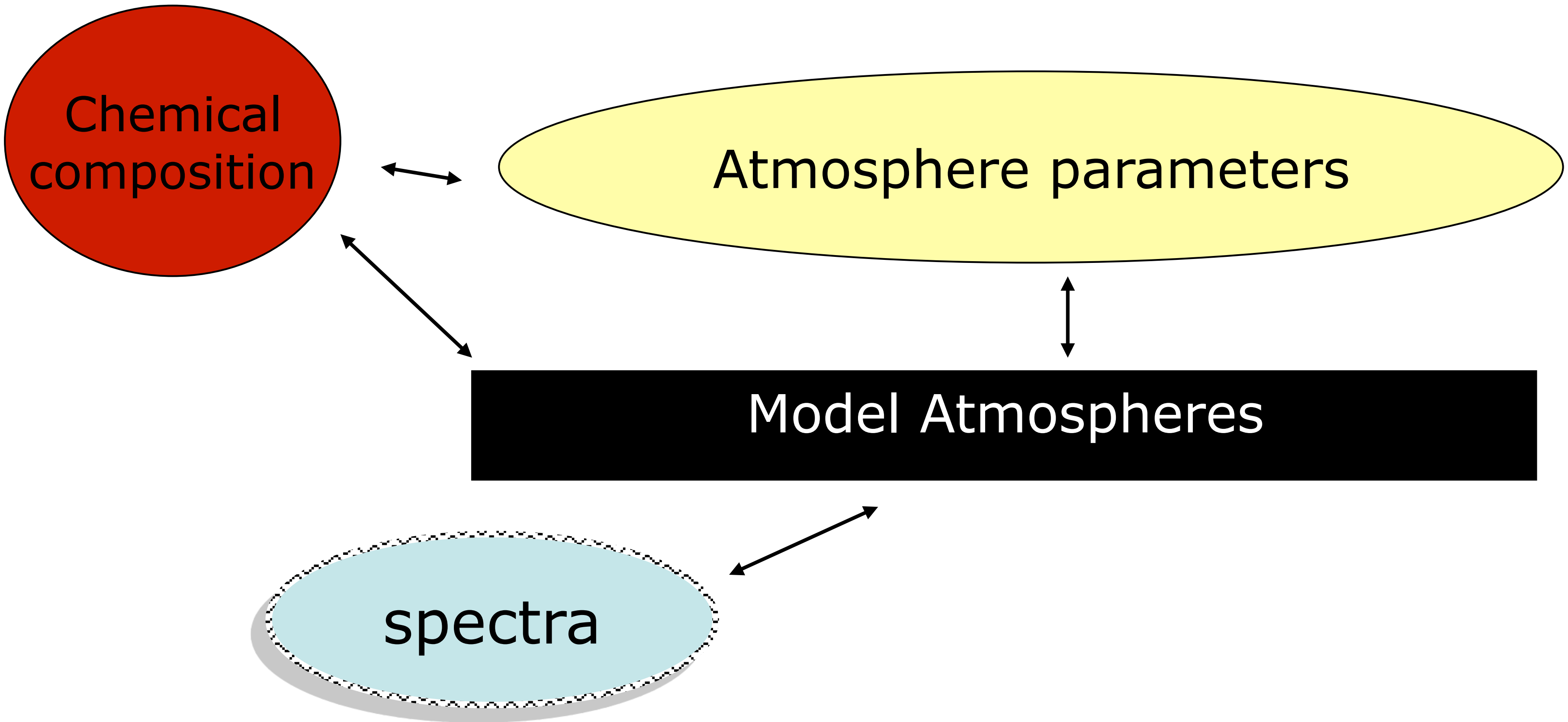
Ankara University, Faculty of Science
Dept. of Astronomy and Space Sciences

14 April 2010

OUTLINE

- From 1-d spectra of the stars to abundance analyses
    - normalization
    - measurement
    - determination of atmosphere parameters
    - abundance analyses using EWs and LTE model atmospheres
- Introduce to the Coude Echellé Spectra of 1.5-m at TÜBİTAK National Observatory (TUG)
    - reduction data within the orders
    - characterictics of the orders
    - abundance analyses of the individual stars
    - comments

Detailed Spectral Analyses



Virtually all our knowledge about stars is derived from the analysis of their radiation, which is emitted in the outermost layers, the stellar atmosphere.

"Spectral analysis" is performed by investigation of the stellar spectra.

"Detailed spectral analysis" gives us information about the elements & their proportions in the stellar atmospheres.

SAMPLE

stars; the two supergiant 4 Lac & ν Cep, δ Scuti star 20 CVn, …

DATA

spectra; on the basis of high S/N, high resolution

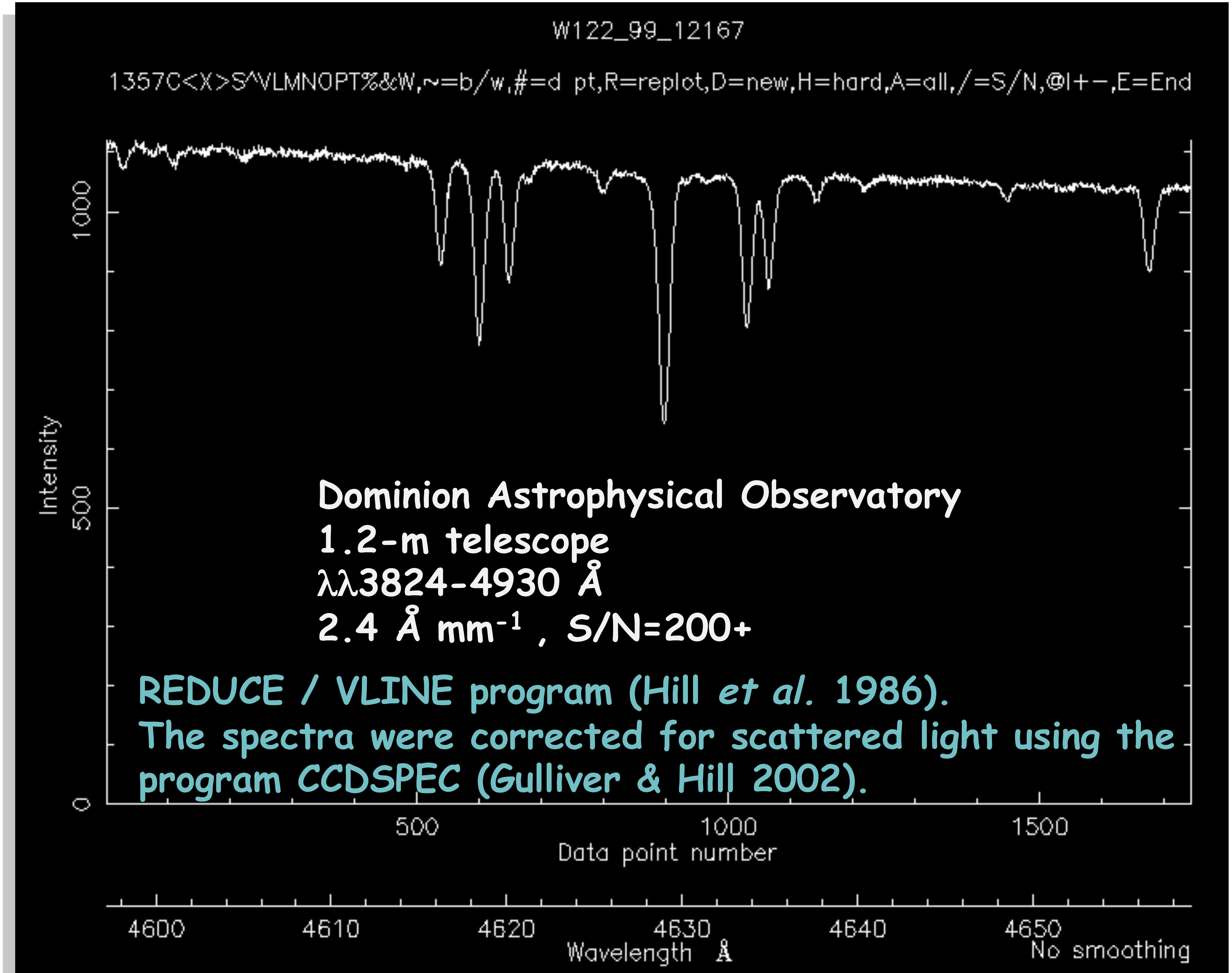
↓ for analysis: the first tool

spectral line ; equivalent width

A common approach for spectral line analyses (in particular for abundance analyses) is to measure and model the integrated line profile, which is expressed in terms of the ***equivalent width***, defined by

$$W_\lambda = \int_0^\infty \frac{F_c - F_\lambda}{F_c} \, d\lambda$$

a) Spectral measurements



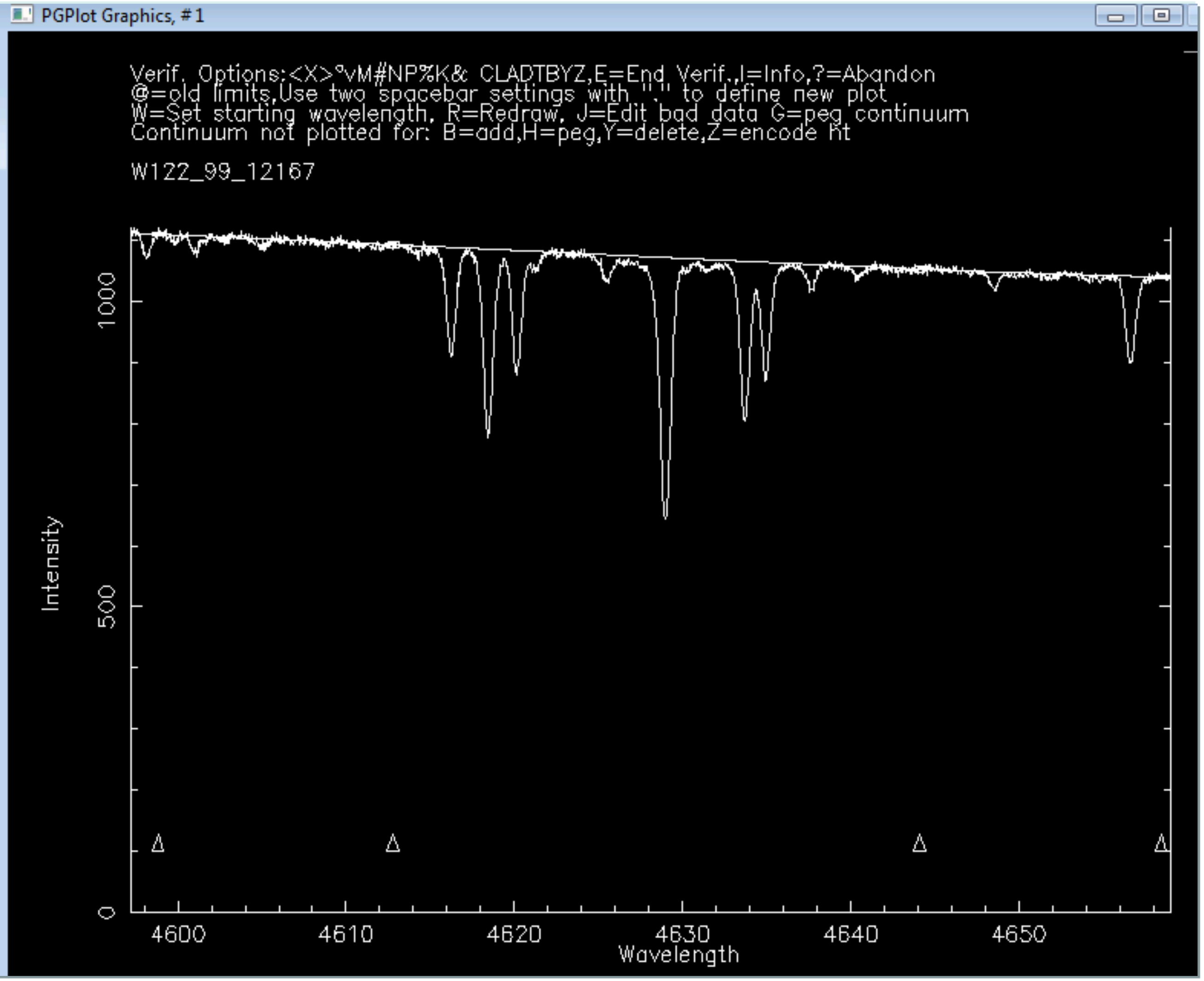
Dominion Astrophysical Observatory
1.2-m telescope
λλ3824-4930 Å
2.4 Å mm^{-1} , S/N=200+

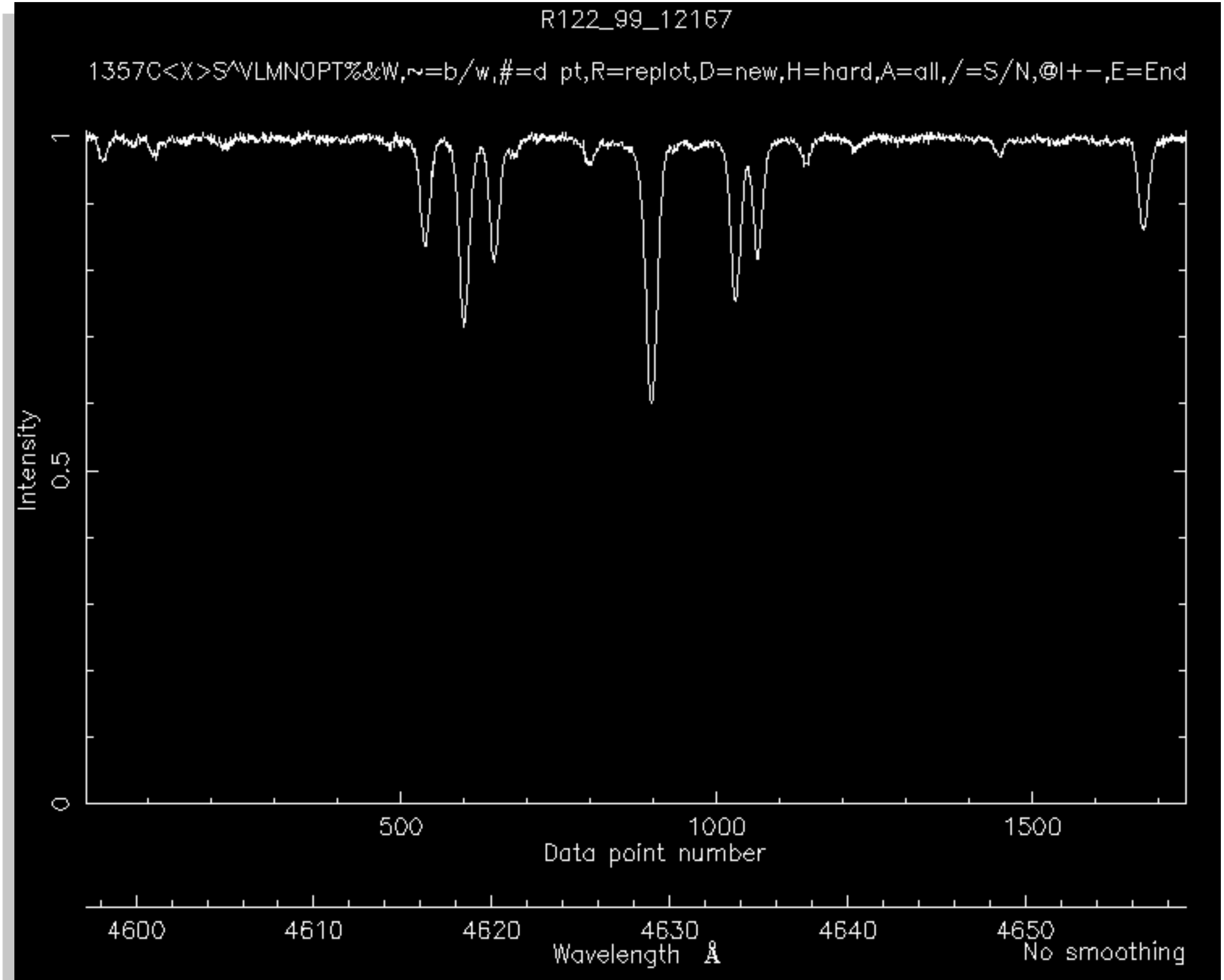
REDUCE / VLINE program (Hill *et al.* 1986).
The spectra were corrected for scattered light using the program CCDSPEC (Gulliver & Hill 2002).

i) continuum adjustment

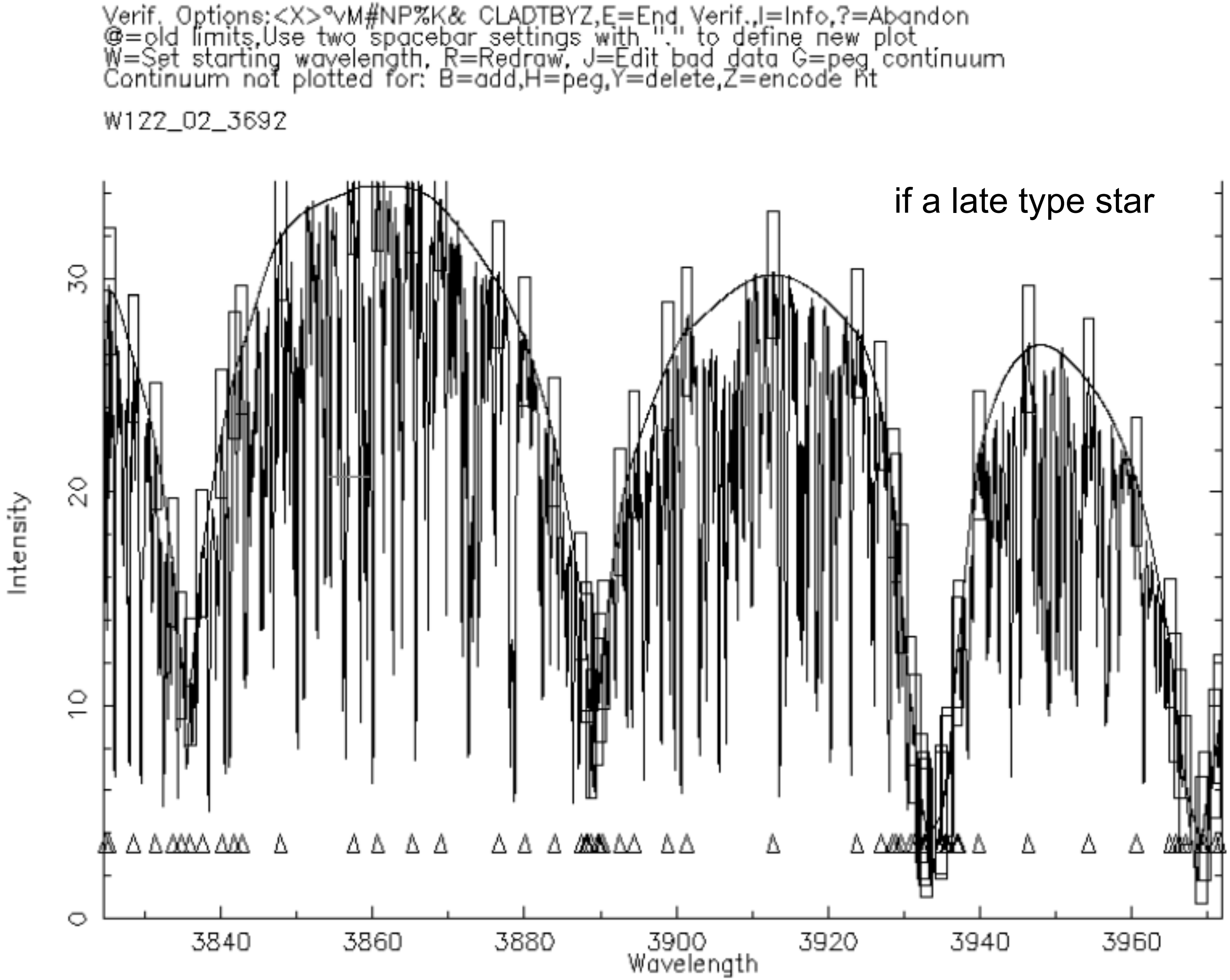
```
 Select OPTIONS: ENTER INDICES (+ or -) of desir
 Complete entries with a 0. Correct them later
 A preceding * denotes a function that can be ru
 For this automatic option, enter index followed
13
15
0
 THIS OKAY? Y, R=restart, L=list anew
Y
 Must now read processed file
 Enter processed FITS disk records-(W,R,I,V,U pr
 To process a master file of FITS records enter
 this file includes a STOP. Once stopped restart
 default values in Options 6,8,10,12,14,15,19--s
 To exit from the file reading, enter EXIT w122_
 Entering fitsin in LINEAR...
 Number of "cards" to the "END" card is
 Am dealing with proper FITS files
 Current file name:
 W122_99_12167.FTS

 Number of header records is            2
  Now inside fitsin2...
 BSCALE=    1.4577241E-02
 BZERO=     642.8378
  About to read some junk...
  Back in fitsin...
 ierr =             0
 Data acquired for
 W122_99_12167
 File: W122_99_12167
           The rectification process      (Option
 Enter continuum file name. To repeat file for s
 enter SAME first, then a prompt will follow for
 Verify/measure mode:V=1st record,W=lam,R=Restar
  Continuum file reordered
 Continuum OK? Y, V or W=Verify again, R=Restart
 S=Yes+Store measured continuum file or J=store
  Continuum file reordered
```

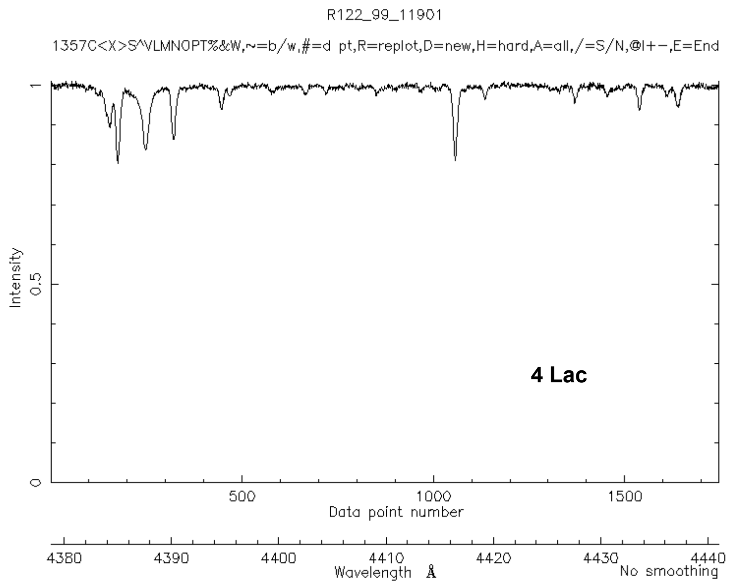


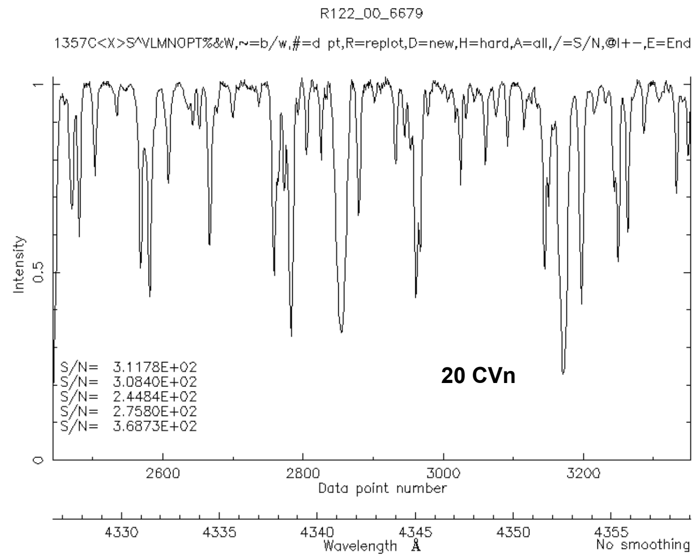


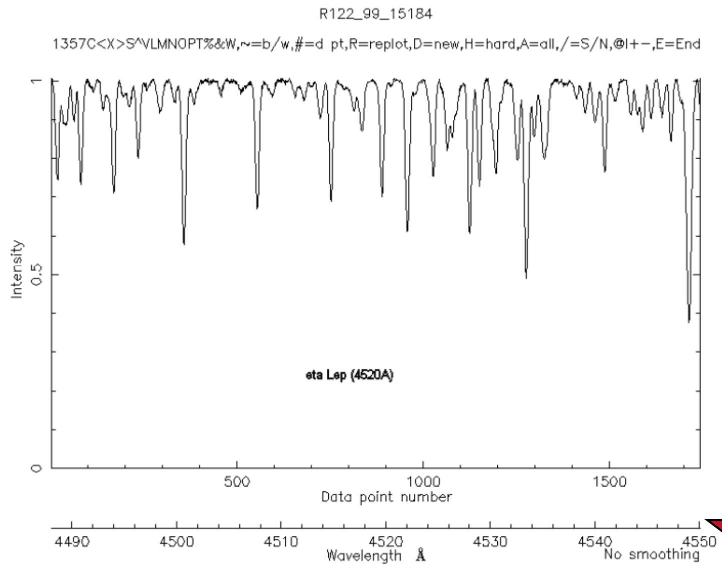
14 April 2010

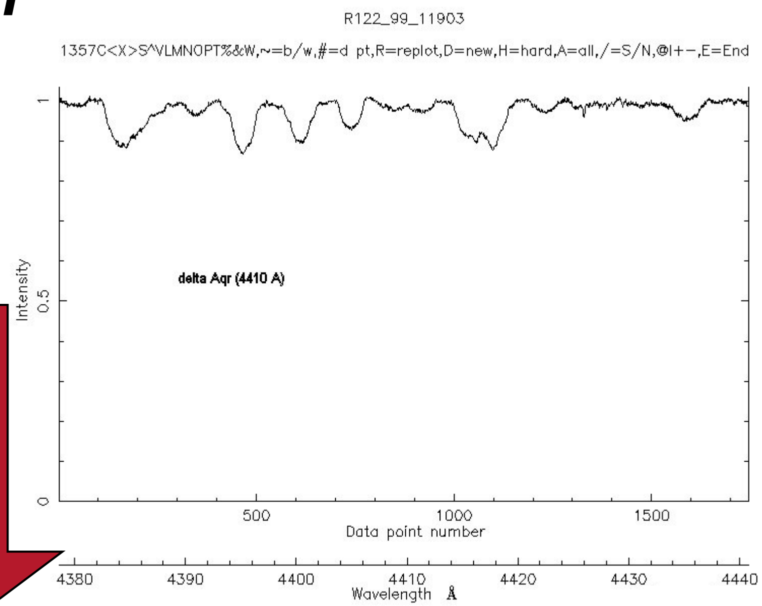

Verif. Options:<X>°vM#NP%K& CLADTBYZ,E=End Verif.,I=Info,?=Abandon
@=old limits,Use two spacebar settings with "." to define new plot
W=Set starting wavelength, R=Redraw, J=Edit bad data G=peg continuum
Continuum not plotted for: B=add,H=peg,Y=delete,Z=encode ht
W122_02_3692
if a late type star
Intensity
Wavelength
0
10
20
30
3840
3860
3880
3900
3920
3940
3960

$v \sin i$







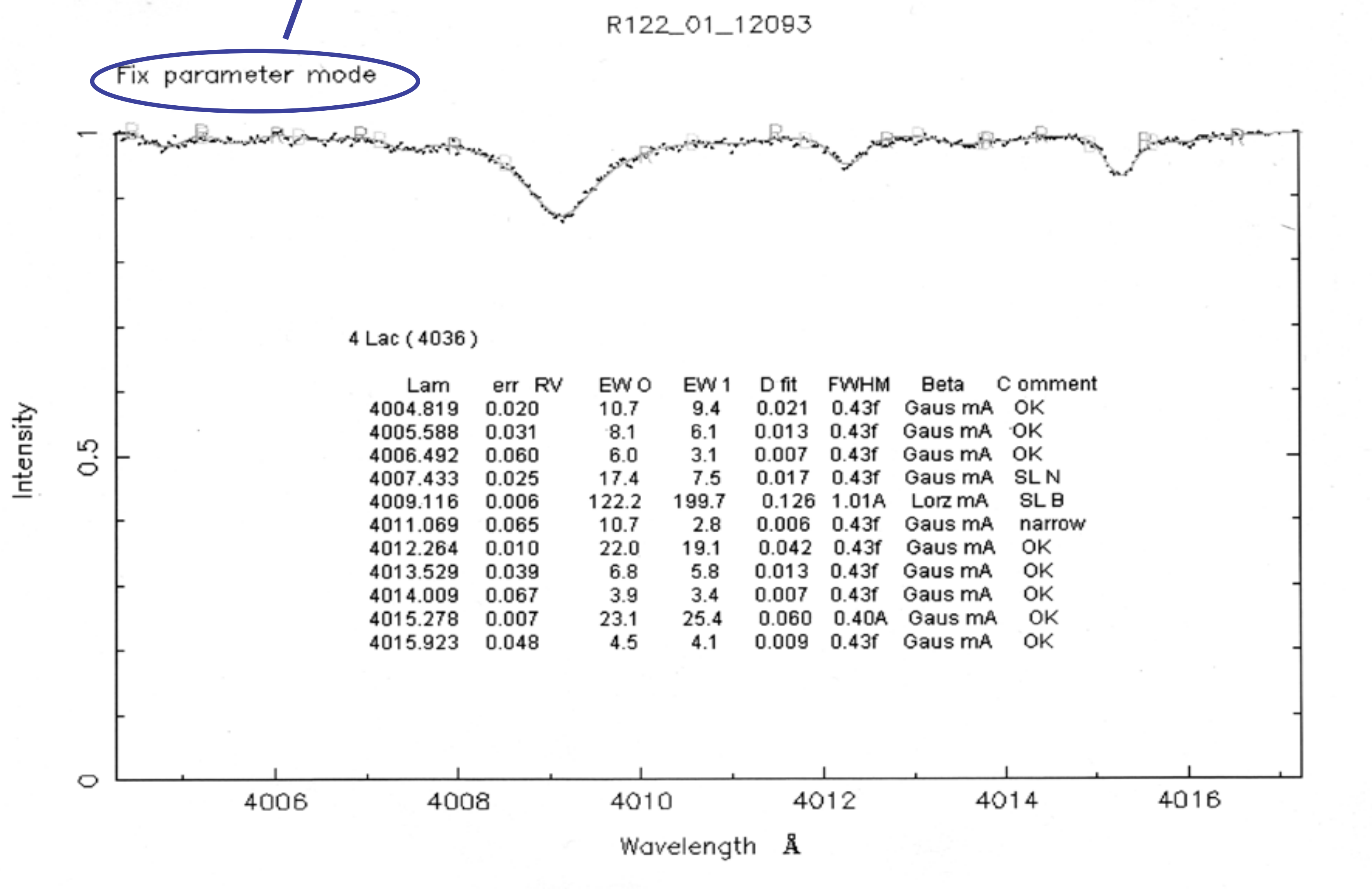


EW

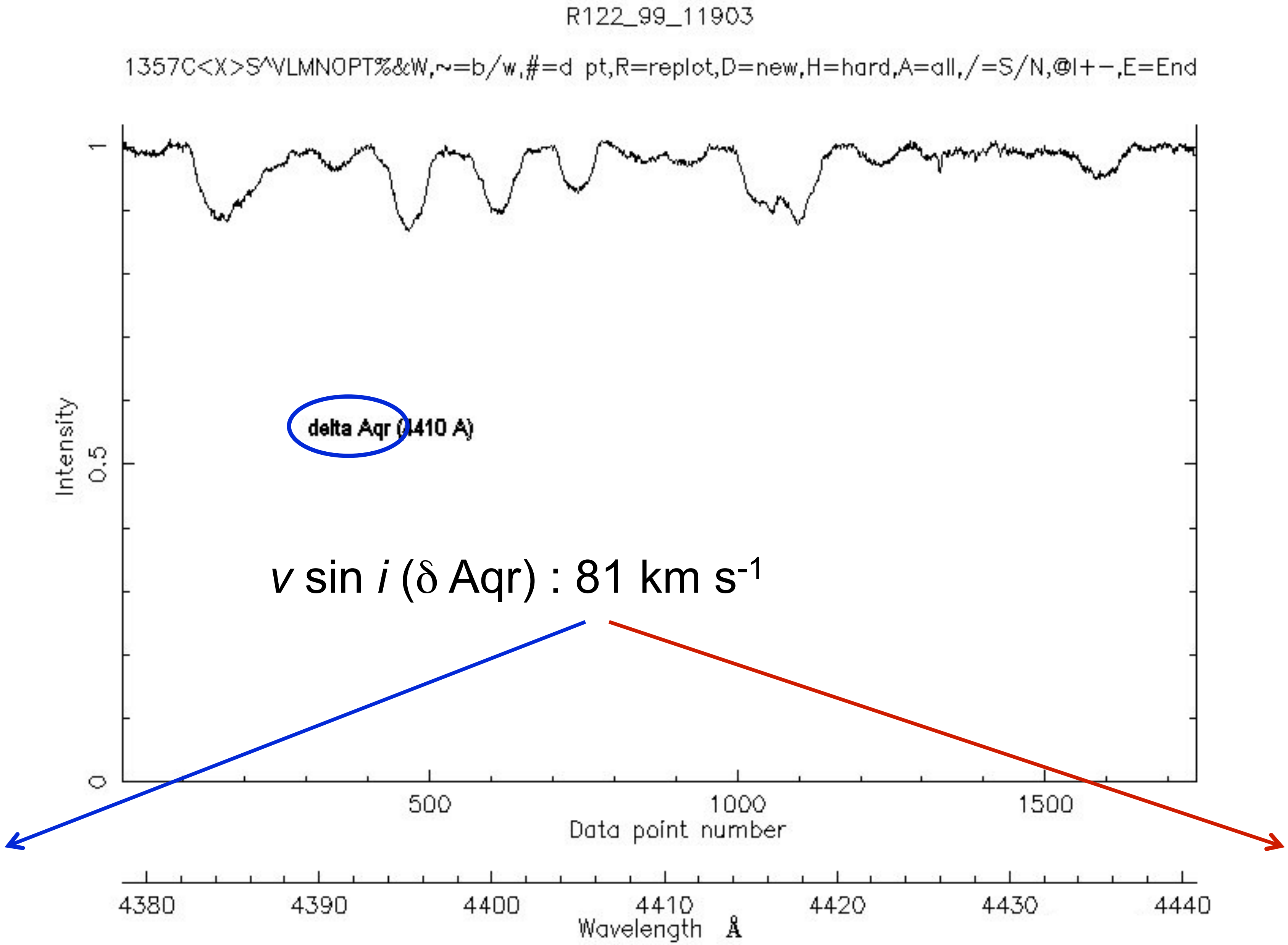
To compare "Obs-Comp": the rotational velocity from line widths

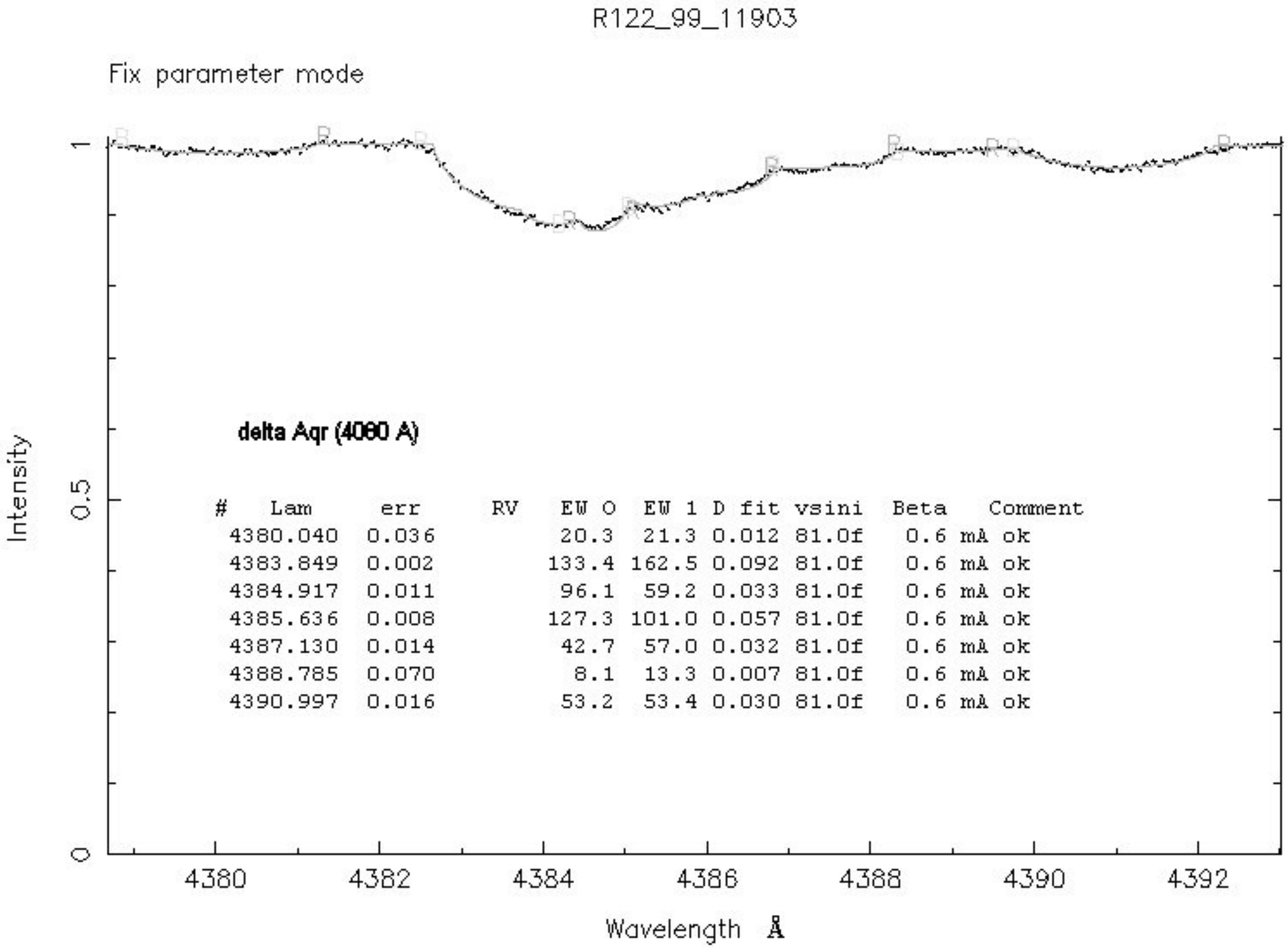
$v \sin i$ (4 Lac) =16 km s^{-1}

ii) profile measurement

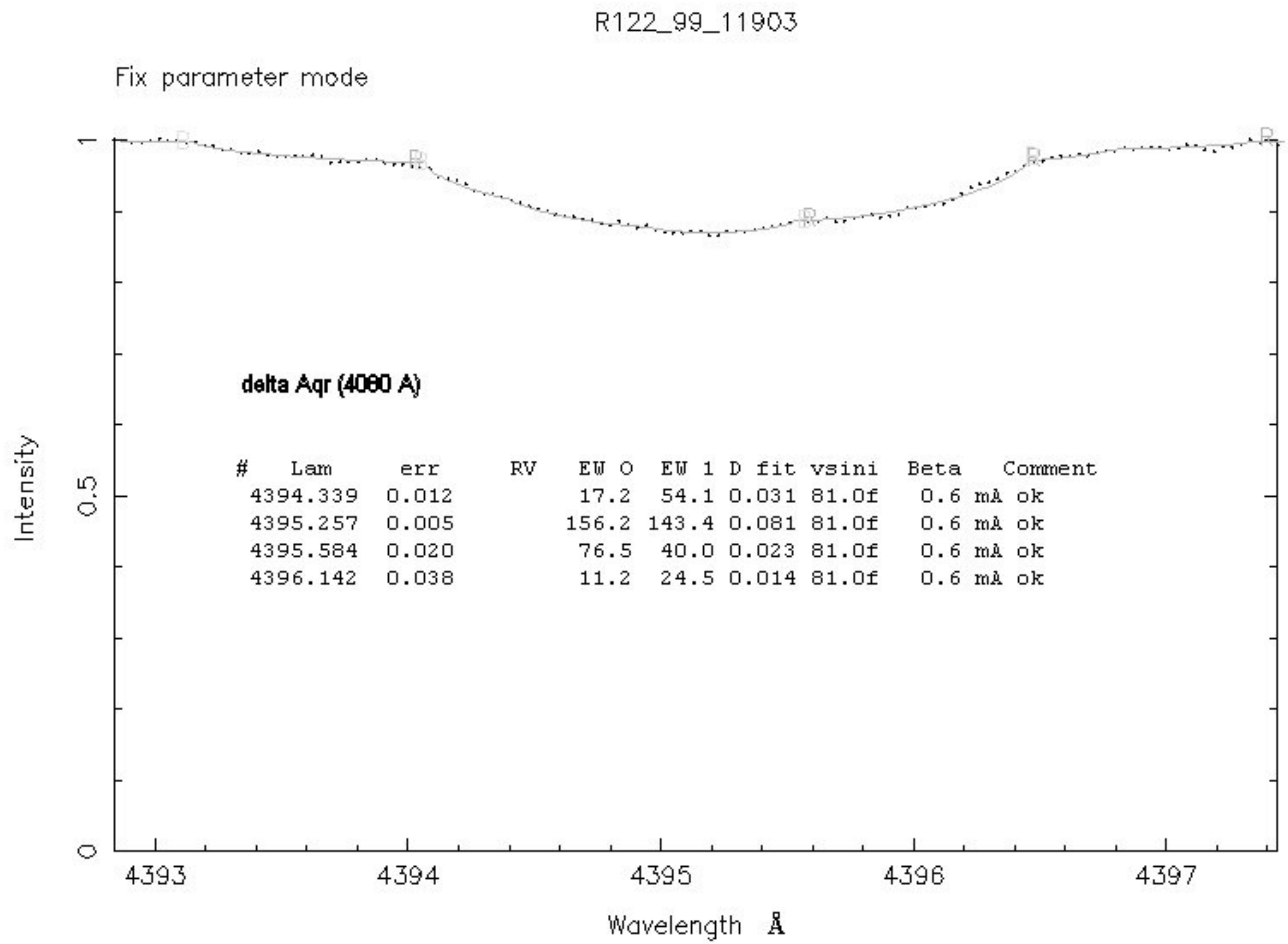


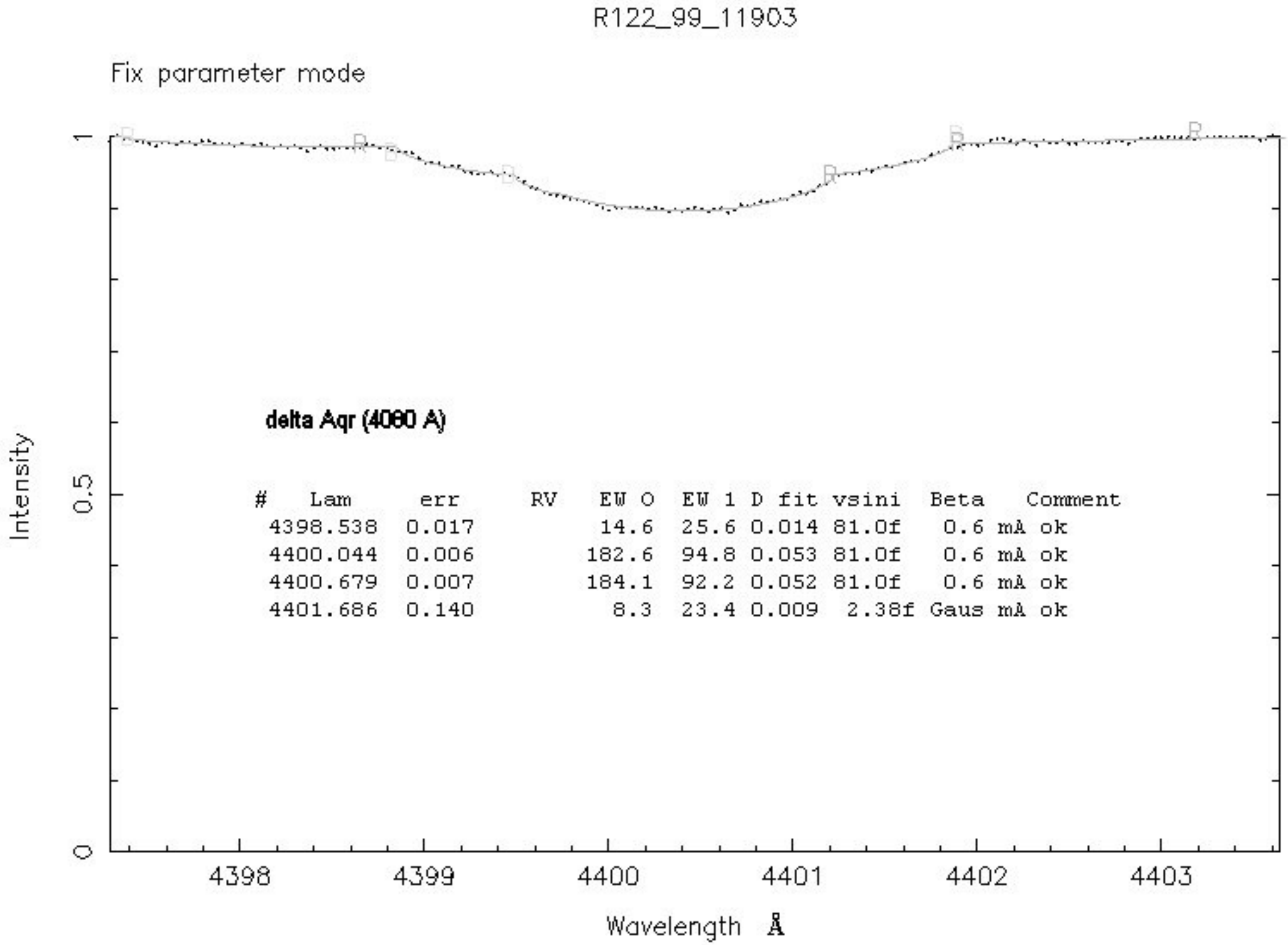
Lam	err RV	EW 0	EW 1	D fit	FWHM	Beta	C omment
4004.819	0.020	10.7	9.4	0.021	0.43f	Gaus mA	OK
4005.588	0.031	8.1	6.1	0.013	0.43f	Gaus mA	OK
4006.492	0.060	6.0	3.1	0.007	0.43f	Gaus mA	OK
4007.433	0.025	17.4	7.5	0.017	0.43f	Gaus mA	SL N
4009.116	0.006	122.2	199.7	0.126	1.01A	Lorz mA	SL B
4011.069	0.065	10.7	2.8	0.006	0.43f	Gaus mA	narrow
4012.264	0.010	22.0	19.1	0.042	0.43f	Gaus mA	OK
4013.529	0.039	6.8	5.8	0.013	0.43f	Gaus mA	OK
4014.009	0.067	3.9	3.4	0.007	0.43f	Gaus mA	OK
4015.278	0.007	23.1	25.4	0.060	0.40A	Gaus mA	OK
4015.923	0.048	4.5	4.1	0.009	0.43f	Gaus mA	OK

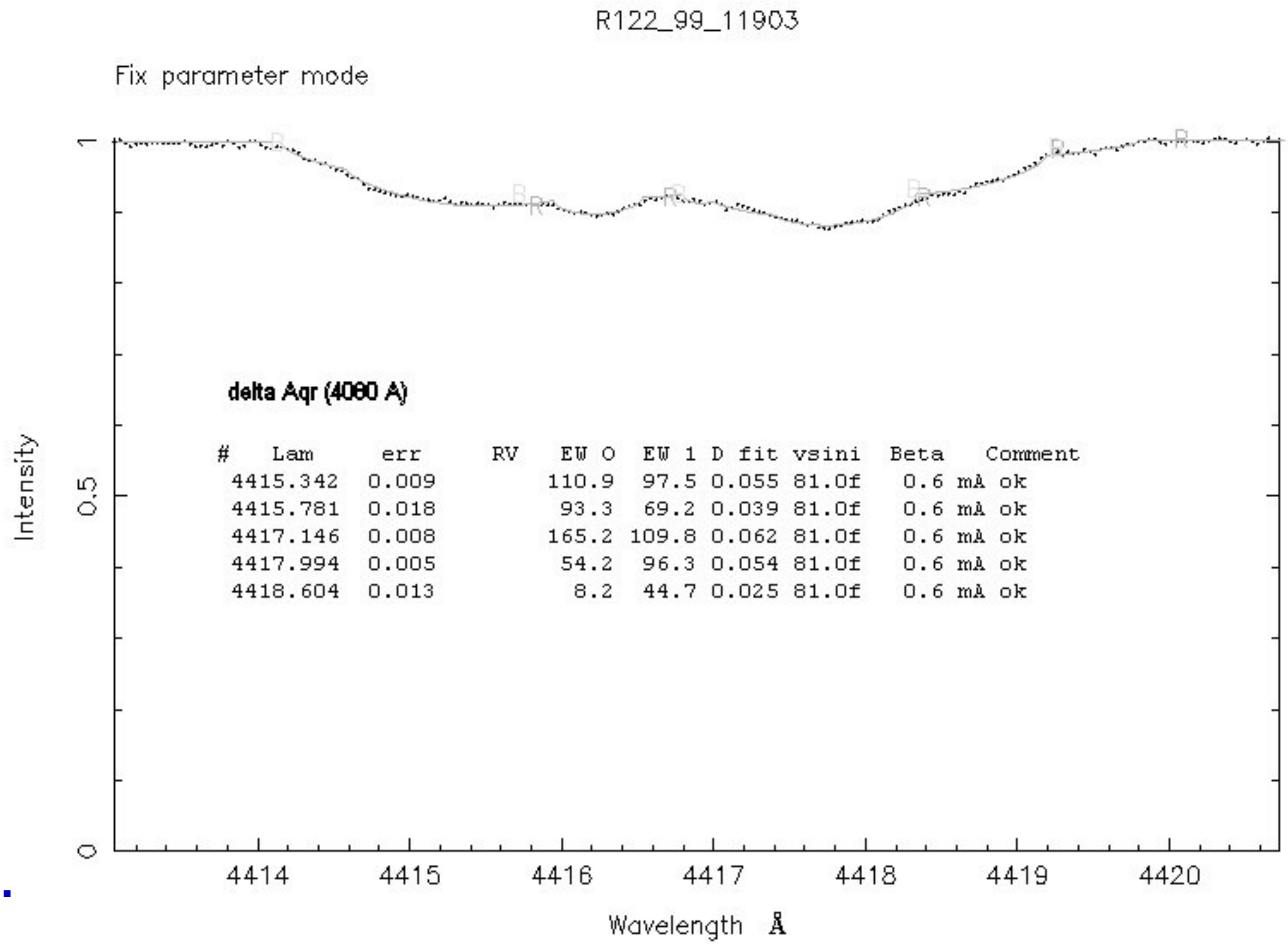

R122_99_11903
1357C<X>S^VLMNOPT%&W,~=b/w,#=d pt,R=replot,D=new,H=hard,A=all,/=S/N,@I+−,E=End
Intensity
delta Aqr (4410 A)
v sin i (δ Aqr) : 81 km s-1
Data point number
Wavelength Å



# Lam	err	RV	EW 0	EW 1	D fit	vsini	Beta	Comment
4380.040	0.036		20.3	21.3	0.012	81.0f	0.6	mA ok
4383.849	0.002		133.4	162.5	0.092	81.0f	0.6	mA ok
4384.917	0.011		96.1	59.2	0.033	81.0f	0.6	mA ok
4385.636	0.008		127.3	101.0	0.057	81.0f	0.6	mA ok
4387.130	0.014		42.7	57.0	0.032	81.0f	0.6	mA ok
4388.785	0.070		8.1	13.3	0.007	81.0f	0.6	mA ok
4390.997	0.016		53.2	53.4	0.030	81.0f	0.6	mA ok


R122_99_11903
Fix parameter mode
delta Aqr (4060 A)
Lam err RV EW 0 EW 1 D fit vsini Beta Comment
4394.339 0.012 17.2 54.1 0.031 81.0f 0.6 mA ok
4395.257 0.005 156.2 143.4 0.081 81.0f 0.6 mA ok
4395.584 0.020 76.5 40.0 0.023 81.0f 0.6 mA ok
4396.142 0.038 11.2 24.5 0.014 81.0f 0.6 mA ok
Intensity
1
0.5
0
4393
4394
4395
4396
4397
Wavelength Å


R122_99_11903
Fix parameter mode
delta Aqr (4080 A)
Lam   err   RV   EW 0   EW 1   D fit   vsini   Beta   Comment
4398.538   0.017   14.6   25.6   0.014   81.0f   0.6   mA ok
4400.044   0.006   182.6   94.8   0.053   81.0f   0.6   mA ok
4400.679   0.007   184.1   92.2   0.052   81.0f   0.6   mA ok
4401.686   0.140   8.3   23.4   0.009   2.38f   Gaus   mA ok
Intensity
1
0.5
0
4398
4399
4400
4401
4402
4403
Wavelength Å



# Lam	err	RV	EW 0	EW 1	D fit	vsini	Beta	Comment
4415.342	0.009		110.9	97.5	0.055	81.0f	0.6 mA	ok
4415.781	0.018		93.3	69.2	0.039	81.0f	0.6 mA	ok
4417.146	0.008		165.2	109.8	0.062	81.0f	0.6 mA	ok
4417.994	0.005		54.2	96.3	0.054	81.0f	0.6 mA	ok
4418.604	0.013		8.2	44.7	0.025	81.0f	0.6 mA	ok

from determining each profile

λ_{obs}(Å)	W_λ (mÅ)	Depth	FWHM		
…	…	…	…		
…	…	…	…		
4257.827	25.5	0.053	0.45	f	
4258.742	8.7	0.018	0.45	f	
4260.149	7.9	0.016	0.45	f	
4261.547	19.0	0.039	0.45	f	
4263.522	11.7	0.024	0.46	f	
4266.819	81.9	0.129	0.60		
4267.465	16.8	0.035	0.46	f	
4268.880	5.7	0.012	0.46	f	
4269.392	7.6	0.016	0.46	f	

3800 Å

....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....

4930 Å

~5000 line profiles were derived for a type F2 III,

~1500 line profiles for a late B type supergiant

iii) wavelength shift

From identifying some of the spectral features, the radial velocity can be found.

using unblended lines → corrected wavelengths

$$V_r = [(\lambda_{obs} - \lambda_{lab}) / \lambda_{lab}].c$$

λ_{obs}(Å)	W_{λ} (mÅ)	Depth	FWHM		λ_{corr}(Å)	
…	…	…	…			
…	…	…	…			
4257.827	25.5	0.053	0.45	f	4258.190	
4258.742	8.7	0.018	0.45	f	4259.105	
4260.149	7.9	0.016	0.45	f	4260.512	
4261.547	19.0	0.039	0.45	f	4261.910	
4263.522	11.7	0.024	0.46	f	4263.885	
4266.819	81.9	0.129	0.60		4267.183	
4267.465	16.8	0.035	0.46	f	4267.829	
4268.880	5.7	0.012	0.46	f	4269.244	

iv) Line Identifications

λ_{obs}(Å)	W_λ (mÅ)	Depth	FWHM		λ_{corr}(Å)	identification	
…	…	…	…	..	…	…	
…	…	…	…	..	…	…	
4257.827	25.5	0.053	0.45	f	4258.190	Fe II (28)4258.155(3)	
4258.742	8.7	0.018	0.45	f	4259.105	S II (66)4259.146(16), (Mn II (I)42	
4260.149	7.9	0.016	0.45	f	4260.512	Fe I (152)4260.4744(35)	
4261.547	19.0	0.039	0.45	f	4261.910	Cr II (31)4261.92(30)	
4263.522	11.7	0.024	0.46	f	4263.885	Fe II(J)4263.895(1)	
4266.819	81.9	0.129	0.60		4267.183	C II(6)4267.003,.258(18,20)	
4267.465	16.8	0.035	0.46	f	4267.829	S II (49)4267.759(21), (Fe I (482)	
4268.880	5.7	0.012	0.46	f	4269.244	Cr II (31)4269.29(10)	
4269.392	7.6	0.016	0.46	f	4269.756	S II (49)4269.724(18)	
…	…	…	…	..	…	…	
…	…	…	…	..	…	…	

Basic source: Moore (1945, 1972)

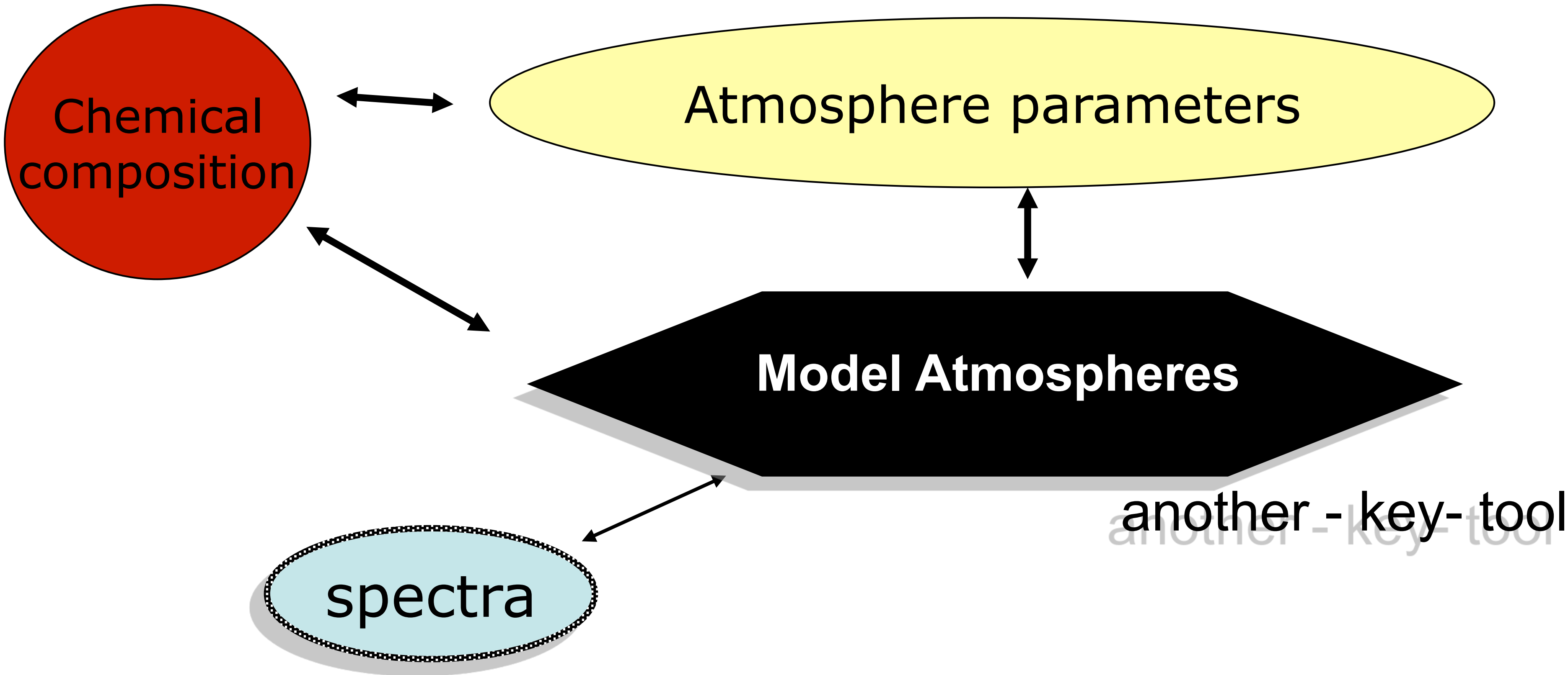
The stellar lines identified from the observed spectra tell us the elements/species in the stellar atmosphere.

4 Lac : **H I, He I, C II, N II, O I, O II, Mg I, Mg II, Al I, Al II, Al III, Si II, Si III, S II, A II, Ca I, Ca II, Sc II, Ti II, V II, Cr II, Mn I, Mn II, Fe I, Fe II, Fe III, Ni II, Sr II, Y II, Zr II, Ba II**

ν Cep : **H I, He I, C I, C II, N I, N II, O I, Mg I, Mg II, Al I, Al II, Si II, S II, Ca I, Ca II, Sc II, Ti I, Ti II, V II, Cr I, Cr II, Mn I, Mn II, Fe I, Fe II, Fe III, Ni I, Ni II, Sr II, Y II, Zr II, Cd I, Ba II, Eu II**

In the BA-type supergiants these are: the light elements helium, carbon, nitrogen and oxygen (CNO), the α–process elements (Ne, Mg, Si, S, Ca), the iron group elements, s–process elements (Sr, Ba) and several other species.

for detailed spectral analyses



After the line profile mesurements using high resolution spectra & state of the art measurement techniques, …

we deduced their effective temperatures, surface gravities, and the microturbulent velocities which characterize their atmospheres
to perform the abundance analysis using the spectra of both supergiants and ATLAS9 LTE model atmospheres with solar abundances for all elements (Kurucz 1993).

Here, the two of the sample stars are the supergiant star.
Supergiants in the literature :

B and A type supergiants are in the visual the brightest stars in those galaxies that are currently forming many stars, that is in spiral and irregular galaxies. Consequently, they are potantially attractive distance and abundance indicators being among the most easily observed stars. Their spectroscopic analyses should provide to information about their parent galaxies.

A summary of BA-type supergiant studies in the early epoch is given by de Jager (1980), Underhill & Doazan (1982) and Wolff (1983).

With the current atmosphere models, some stars have been studied. In the pioneering study of Venn (1995a,b) over twenty Galactic A-type supergiants were analysed for abundances, in part using non-LTE methods. She limitted the sample to lower luminosity supergiants (Ib and II) to improved the accuracy of LTE assumptions made in the atmospheric analysis; i.e.., the
A-type supergiants are difficult stars to work with since their large, tenuous atmospheres and high luminosities put them near the limits of radiative and hydrostatic equlibrium.

Classical LTE models are found to be a fairly good representation for the atmospheres of the majority of main sequence stars, except for the hottest objects, where non-LTE becomes important. In the case of supergiants, however, a full account of the effects of spherical extension, velocity fields and deviations from LTE would be desirable, as clear evidence for their presence is found in observed spectra. Emission lines and an IR-excess in the continuum radiation indicate spherical extension; the presence of lines with P-Cygni profiles tells of velocity fields associated with mass-loss; finally, abundances in individual stars depend on the strength of the lines analysed, or abundances in an ensemble of stars correlate with stellar temperature or with luminosity (i.e. surface gravity), which all point to deviations from LTE. Such models has been currently under development (Aufdenberg 2000). He presents a preliminary spherical non-LTE model atmosphere for Deneb (α Cyg, A2 Iae) using the PHOENIX code. But, he used solar abundances and did not consider how changing the photospheric abundances from these values would affect the atmosphere.

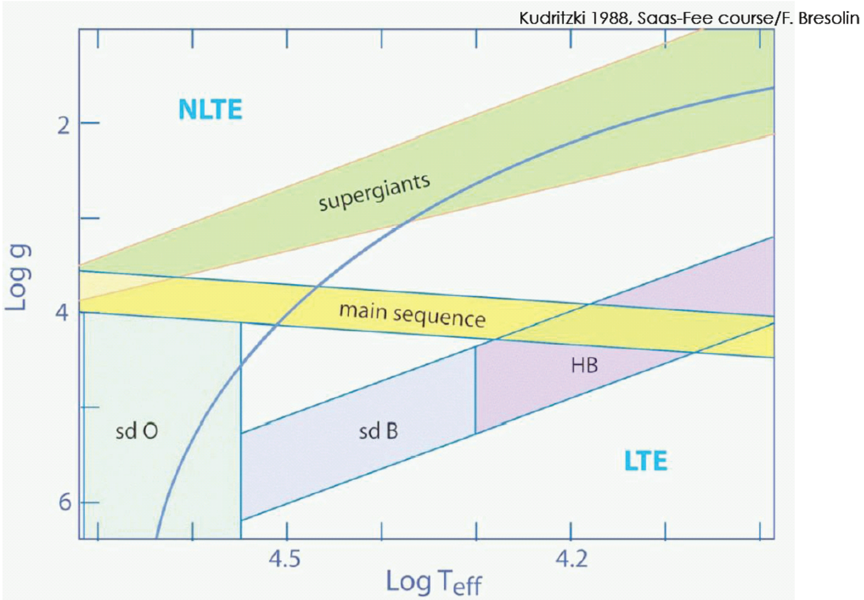
For supergiants the quantitative spectroscopy have been done by Przybilla et al. (2001a,b,c,…):

- Model atoms
- Model atmospheres
- Quality of observed spectra
- Quantitative analysis (atmosphere pamaters adopted)
- Other input (EWs, ...)
- .....

Non-LTE model atoms

Ion	Source
H	Przybilla & Butler (2004)
He I	Przybilla (2005)
C I/II	Przybilla et al. (2001b), Nieva & Przybilla (2006, 2008)
N I/II	Przybilla & Butler (2001)
O I	Przybilla et al. (2000)
Mg I/II	Przybilla et al. (2001a)
S II	Vrancken et al. (1996), with updated atomic data
Ti II	Becker (1998)
Fe II	Becker (1998)

Model atmospheres for Hot Stars



v) The atmosphere parameters:
T_{eff} , log g , ξ

Stellar parameters (T_{eff}, log g, ξ) are derived for individual stars.

…uses criteria such as fitting the energy distributions and Balmer line profiles as well as ionization equilibria for several elements with two stages of ionization - eg. Fe, Cr, Ti, Mg, ...

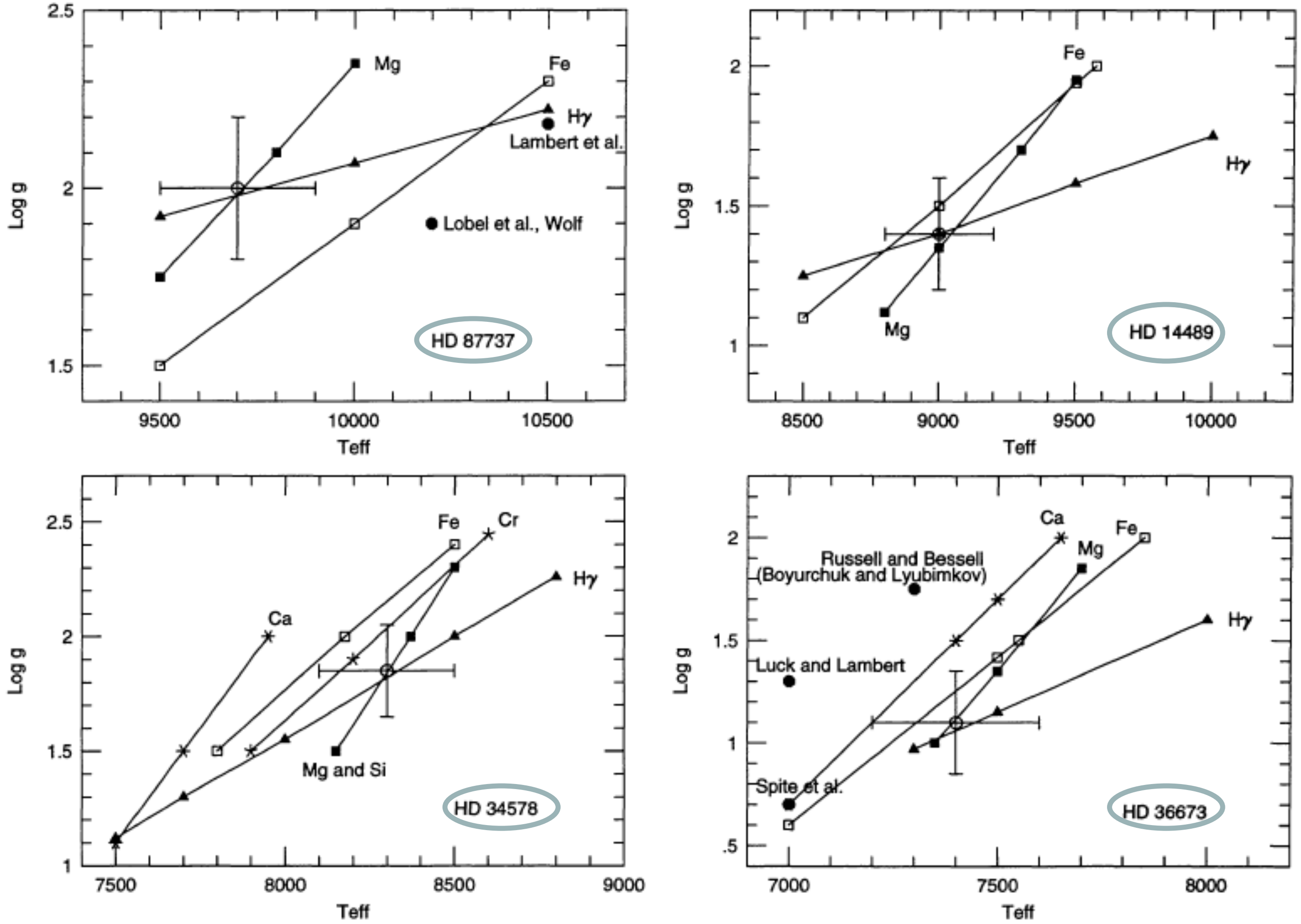
Ionization Equilibria :

– The abundances obtained from different ionization stages of the an element must agree: for example; Fe I/II, Mg I/II

$$\log \varepsilon(\mathrm{Fe\ I}) = \log \varepsilon(\mathrm{Fe\ II})$$

$$\log \varepsilon(\mathrm{Mg\ I}) = \log \varepsilon(\mathrm{Mg\ II})$$

T_{eff} - log g Diagram



Venn (1995a)

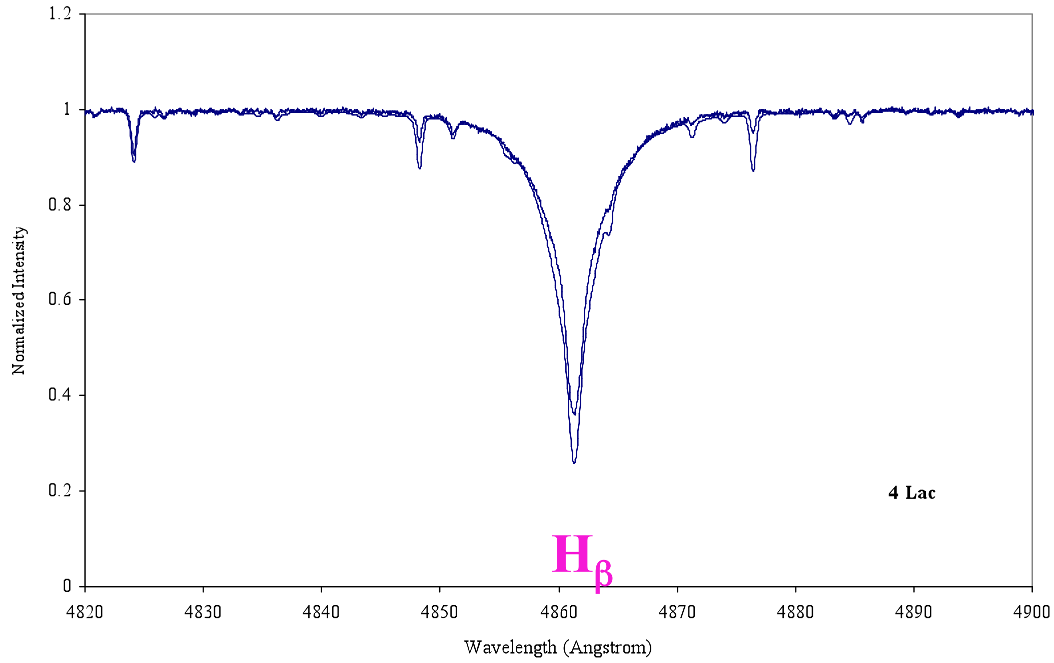
Very useful diagnostic

- in theory all diagnostics should give unique T_{eff} and log g solution.

- in practice there is a region in T_{eff} and log g space that contains the solution and its uncertainty.

4 Lac

(a) **H_β** and **$H\gamma$** profiles

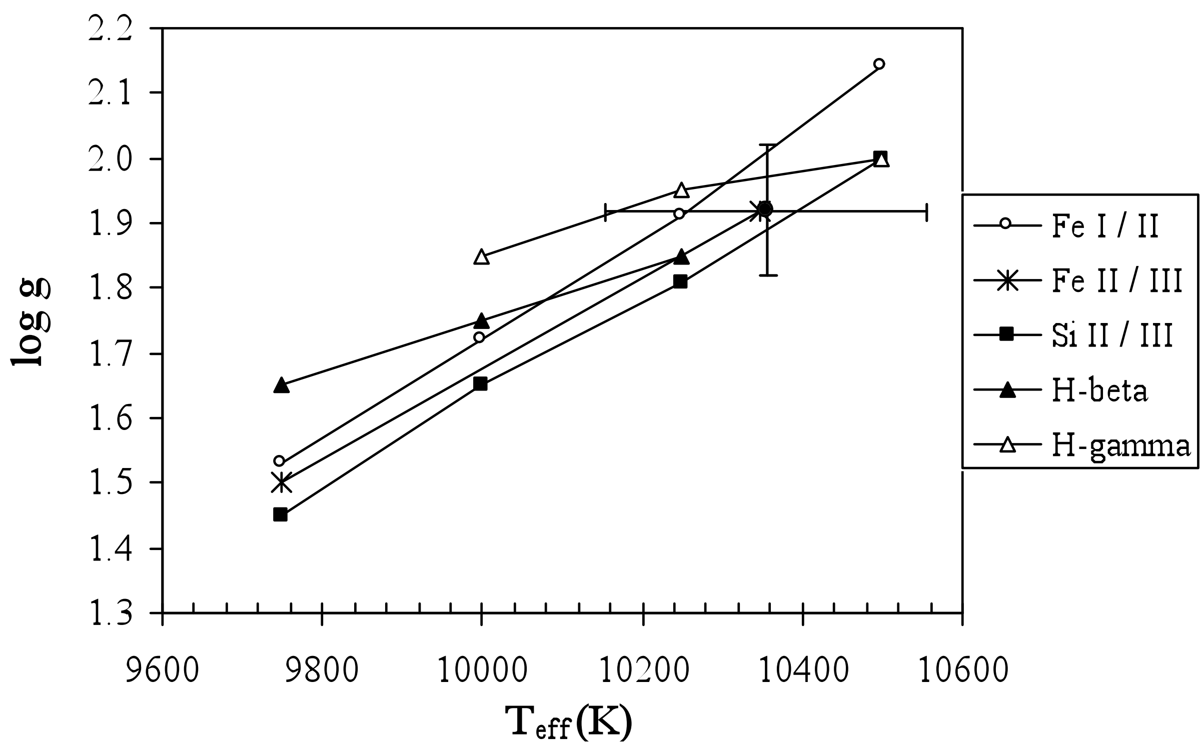


(b) Ionization equilibrium using **Fe I/II**, **Fe II/III** and **Si II/III**

- **Iron:** log ε(Fe I) = log ε(Fe II)
  log ε(Fe II) = log ε(Fe III)
  Silicon: log ε(Si II) = log ε(Si III)

- **Comparison of observed and theoretical profiles of H_β and H_γ**

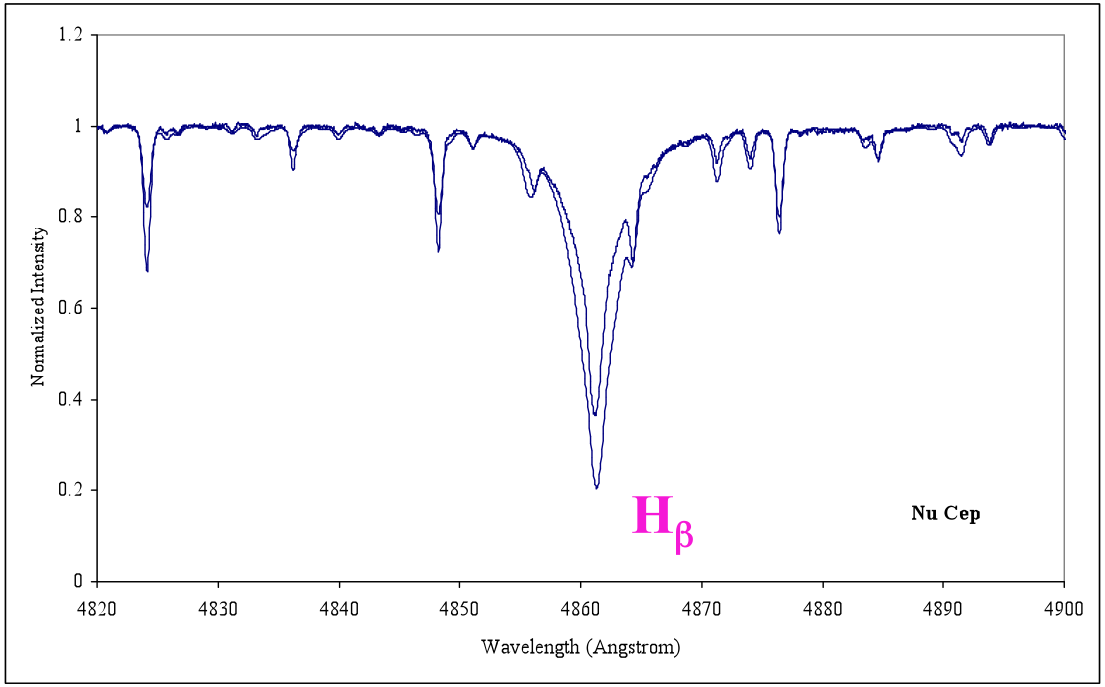
4 Lac, Kiel Diagram



T_{eff} = 10350 K log g = 1.92

ν Cep

(a) H_β and $H\gamma$ profiles



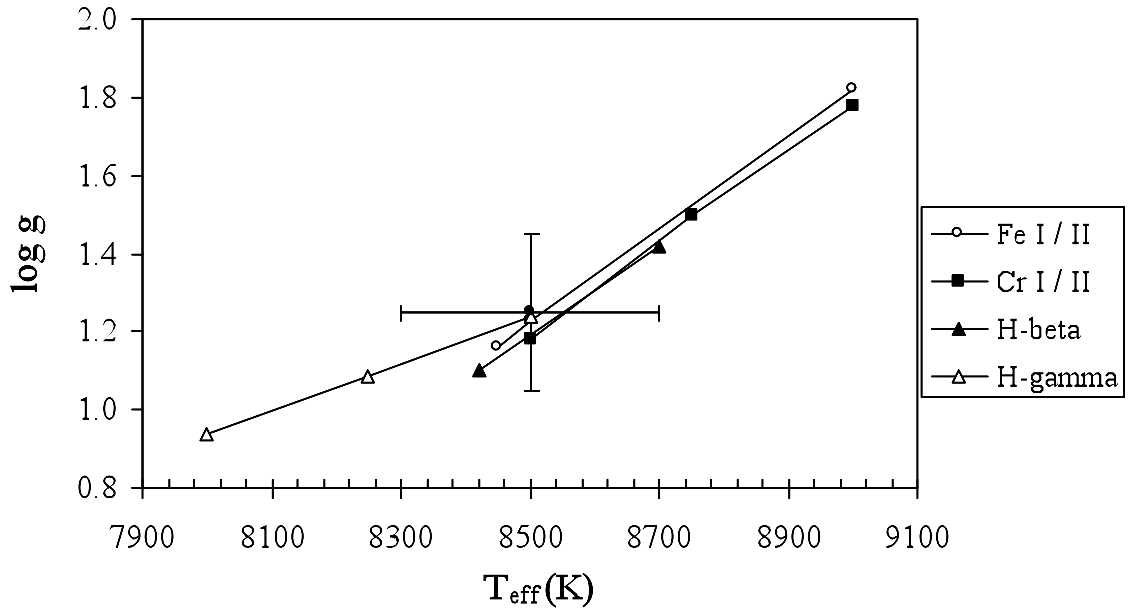
(b) Ionization equilibrium using Fe I/II and Cr I/II

- **Iron:** log ε(Fe I) = log ε(Fe II)

  Chromium: log ε(Cr I) = log ε(Cr II)

- **Comparison of observed and theoretical profiles of H_β and H_γ**

ν Cep, Kiel Diagram

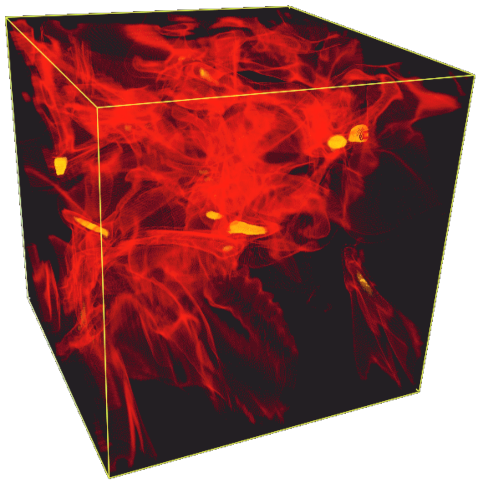


T_{eff} = 8500 K log g = 1.25

Spectral line broadenings also due to turbulence motions (Struve & Elvey 1934). The motions of the photospheric gases introduce Doppler shifts which broaden spectral lines. Astronomers use two asymptotic approximations:

a) the size of the turbulent elements is small compared with unit optical depth, the microturbulence limit, and

b) the size of the turbulent elements is large compared with unit optical depth, the macroturbulence limit. However, in reality, there is a range of turbulence element sizes which affect the observed line profiles.

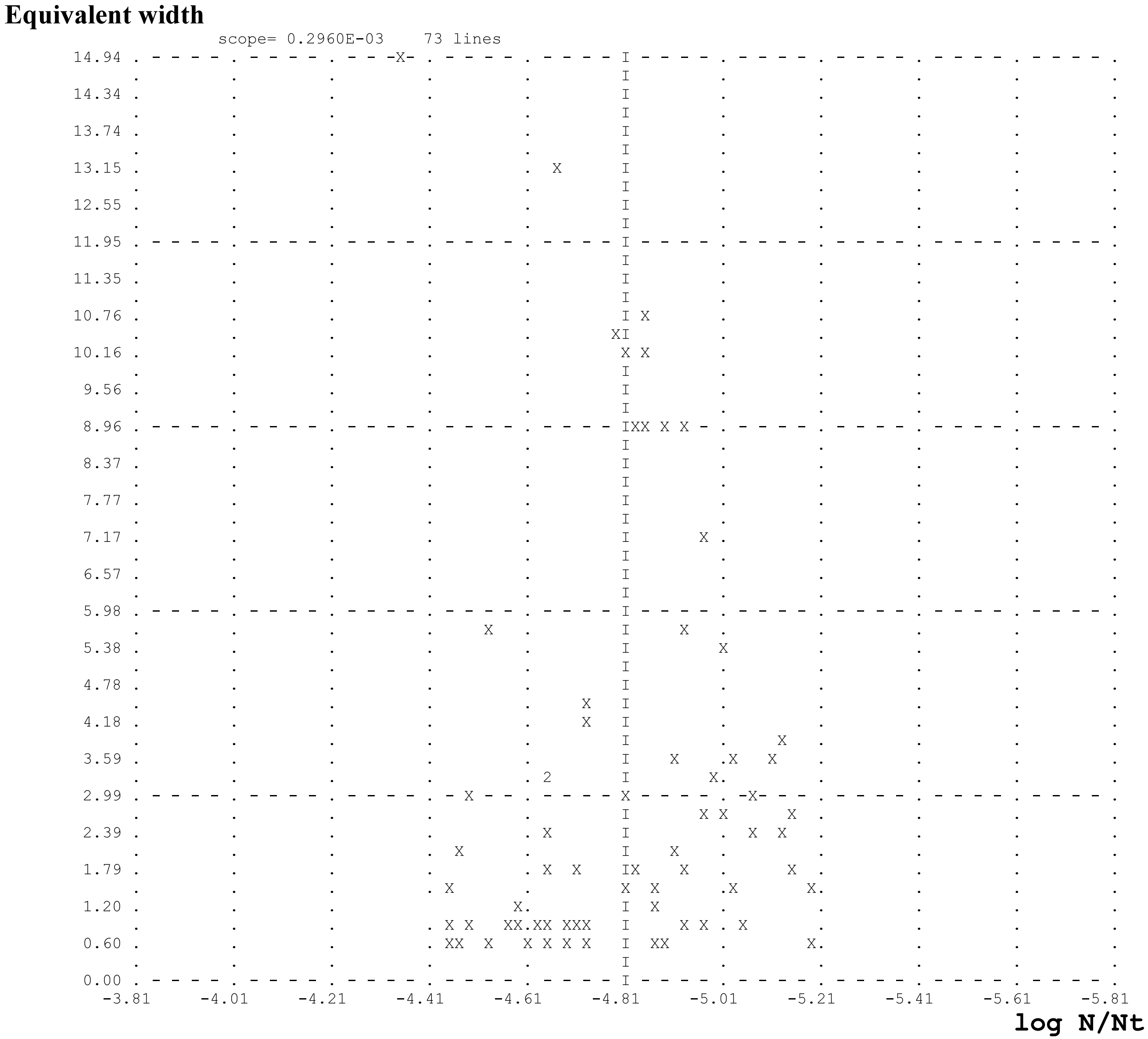


Microturbulent velocity; ξ

This changes the equivalent width of a line profile.

The elemental abundances are calculated using the EWs. Thus the determination of microturbulence is important for the atmosphere analysis.

To determine the microturbulent velocity we derived abundances for Fe I, Fe II, Ti II and Cr II lines for a range of *assumed microturbulent values* using WIDTH9 (Kurucz 1993). The adopted ξ values for each species resulted in no dependence of the derived abundances on equivalent width.



4 Lac: Fe II lines; Abundances & EW; using EW's and atomic data by WIDTH9 program (T_{eff} = 10350°K, log g = 1.92, ξ = 2.7 kms^{-1})

minimum

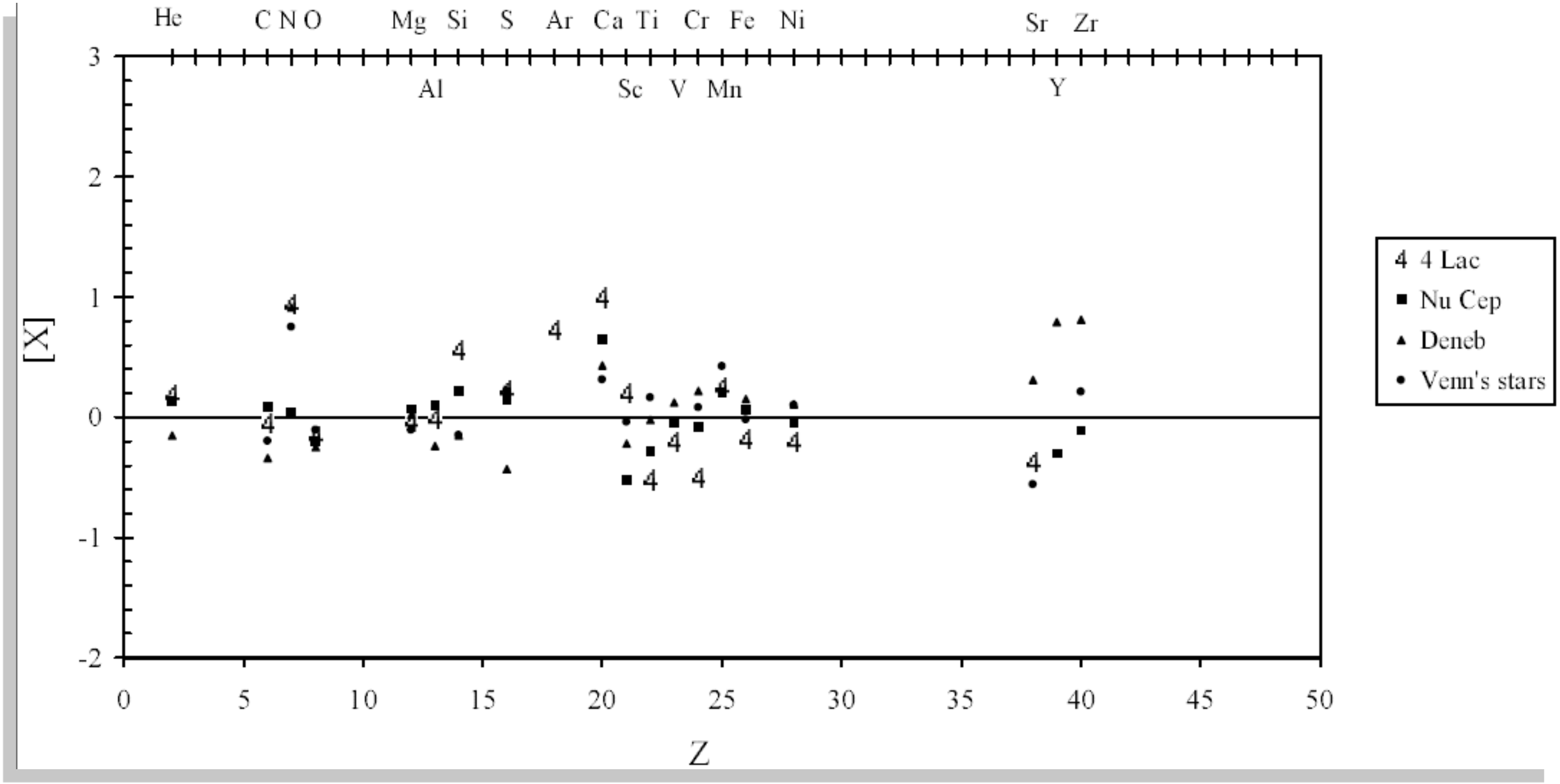
slope | scatter

Tablo. Mikroturbulences

	Ion	n	ξ_1 (km s^{-1})	log N/N_T	ξ_2 (km s^{-1})	log N/N_T
4 Lac	Fe II	71	2.5	-4.8±0.2	2.8	-4.8±0.2
		adopted	$\xi = 2.7$ km s^{-1}			
ν Cep	Cr II	30	5.2	-6.4±0.2	5.1	-6.4±0.2
	Ti II	39	5.5	-7.4±0.2	5.5	-7.4±0.2
	Fe II	61	4.8	-4.5±0.2	5.5	-4.5±0.2
		adopted	$\xi = 5.2$ km s^{-1}			

Table 5. Comparison of abundances for 4 Lac, ν Cep and the Sun.

Species	4 Lac			ν Cep			Sun[1]
	n	log N/N_H	$[X]^2$	n	log N/N_H	$[X]^2$	
He I	9	−0.82 ± 0.06	+0.18	5	−0.87 ± 0.02	+0.13	−1.00
C I	–	–	–	1	−3.52	−0.07	−3.45
C II	1	−3.47	−0.02	1	−3.43	+0.02	−3.45
N I	–	–	–	2	−3.99 ± 0.05	+0.04	−4.03
N II	8	−3.04 ± 0.17	+0.99	–	–	–	−4.03
O I	3	−3.27 ± 0.14	−0.15	2	−3.33 ± 0.18	−0.21	−3.12
Mg II	9	−4.56 ± 0.12	−0.14	6	−4.45 ± 0.05	−0.03	−4.42
Al II	1	−5.53	0.00	1	−5.43	+0.10	−5.53
Si II	3	−3.87 ± 0.14	+0.58	7	−4.26 ± 0.22	+0.19	−4.45
Si III	3	−3.90 ± 0.09	+0.55	–	–	–	−4.45
S II	21	−4.45 ± 0.18	+0.22	7	−4.52 ± 0.15	+0.15	−4.67
Ar II	2	−4.75 ± 0.24	+0.73	–	–	–	−5.48
Ca I	1	−4.64	+1.00	2	−4.99 ± 0.17	+0.65	−5.64
Sc II	2	−8.63 ± 0.17	+0.20	4	−9.34 ± 0.22	−0.51	−8.83
Ti II	19	−7.50 ± 0.17	−0.52	47	−7.27 ± 0.26	−0.29	−6.98
V II	3	−8.20 ± 0.19	−0.20	18	−8.06 ± 0.22	−0.06	−8.00
Cr I	–	–	–	2	−6.44 ± 0.03	−0.11	−6.33
Cr II	17	−6.83 ± 0.21	−0.50	36	−6.29 ± 0.22	−0.04	−6.33
Mn II	7	−6.44 ± 0.27	+0.17	17	−6.40 ± 0.21	+0.21	−6.61
Fe I	8	−4.66 ± 0.17	−0.16	54	−4.47 ± 0.23	+0.03	−4.50
Fe II	73	−4.70 ± 0.24	−0.20	72	−4.40 ± 0.20	+0.10	−4.50
Fe III	4	−4.36 ± 0.14	+0.14	1	−4.61	−0.11	−4.50
Ni II	7	−5.95 ± 0.20	−0.20	4	−5.79 ± 0.02	−0.04	−5.75
Sr II	2	−9.40 ± 0.00	−0.37	–	–	–	−9.03
Y II	–	–	–	2	−10.06 ± 0.13	−0.30	−9.76
Zr II	–	–	–	5	−9.51 ± 0.26	−0.11	−9.40



He
C N O
Mg
Si
S
Ar
Ca
Ti
Cr
Fe
Ni
Sr
Zr
Al
Sc
V
Mn
Y
3
2
1
0
-1
-2
[X]
0
5
10
15
20
25
30
35
40
45
50
Z
4 4 Lac
Nu Cep
Deneb
Venn's stars

The detailed spectral analyses of the individual supergiants help to illuminate the evolution of massive stars.

There are several evolutionary scenarios based on the abundances of *carbon&nitrogen&oxygen*.

These models depend on whether or not the surface abundances reflect CNO-core processed material in the photosphere.

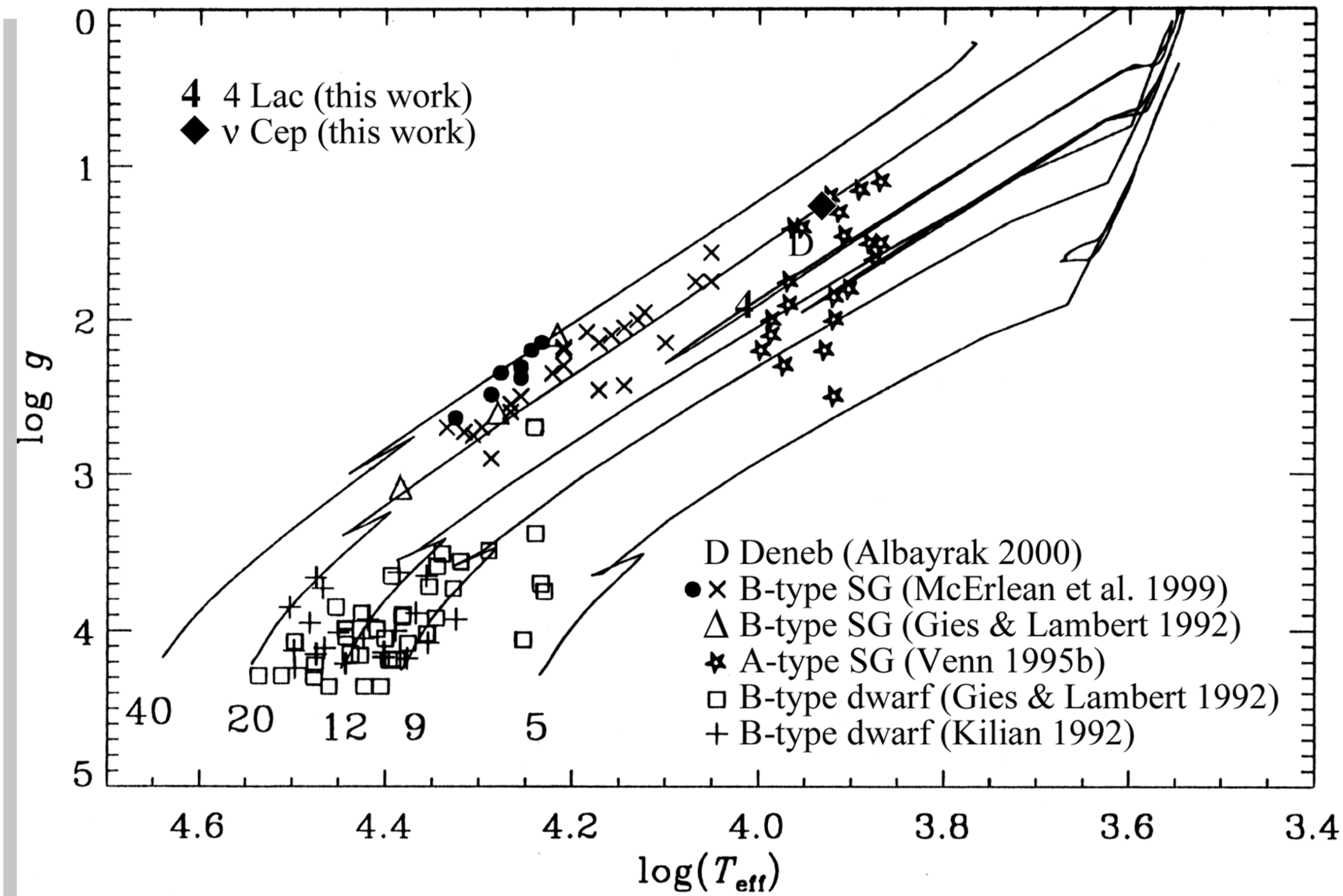
◆ The CNO surface abundances of a supergiant are its ZAMS surface values that have possibly been modified by mixing (dredge-up) between the interior and outer envelope of a star. Since CNO elements only act as catalysts during hydrogen burning for a massive main sequence star, the reduction of abundances of C and to a lesser extent of O, and the increase of the abundance of N with the sum of nuclei remaining constant is predicted.

4 Lac (N_{LTE}: 0.99 dex)

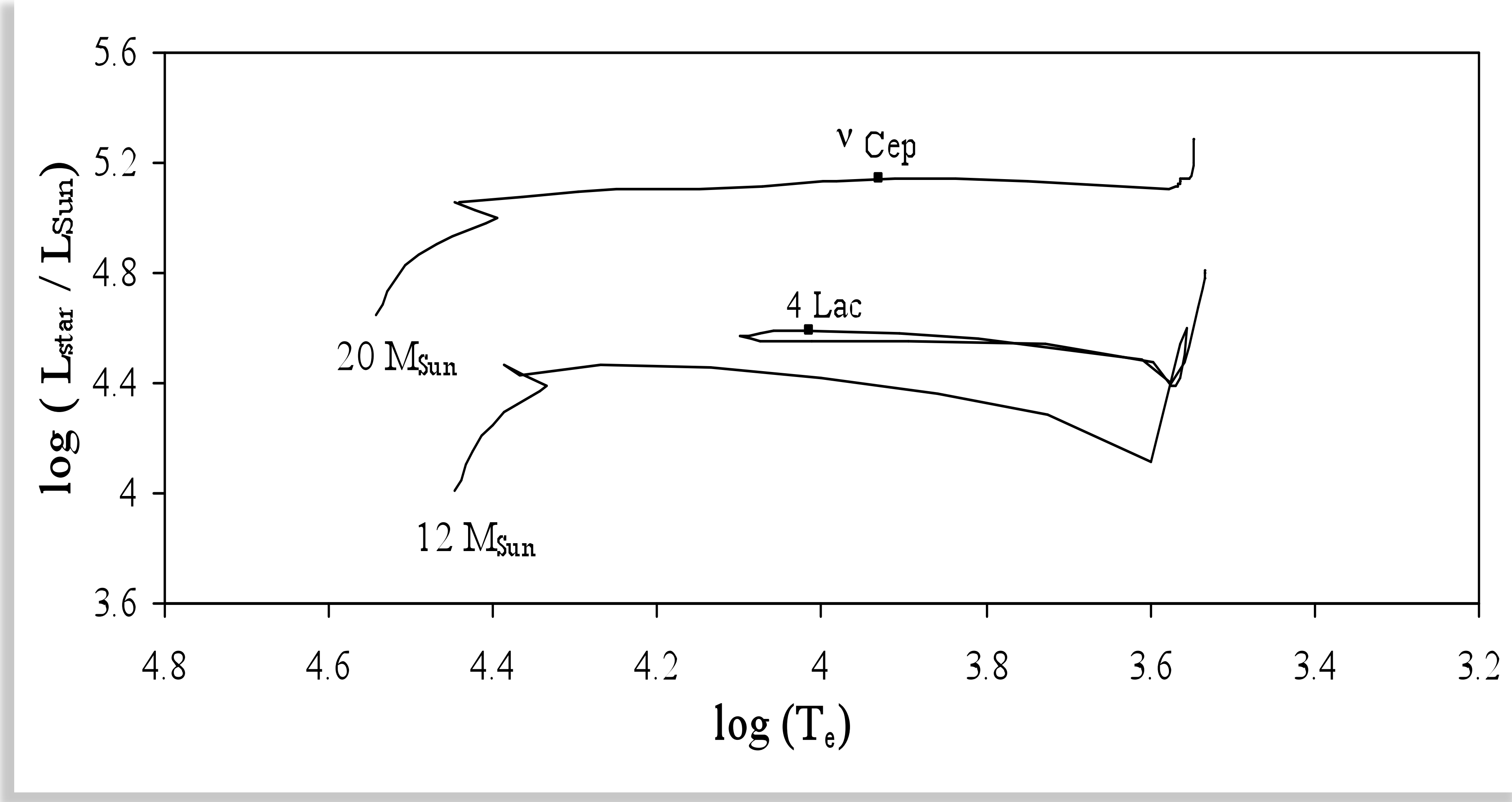
◆◆ Another model suggests that the stars iniae helium core burning without visiting the red giant branch , hence such stars evolve directly from the main sequence. After He ignition in the core, the star is essentially in thermal equilibrium throughout He-core burning and remains a blue supergiant. In this scenario, no mixing with deeper layers is anticipated, hence the CNO abundances should be solar (e.g., like those of main sequence B-type stars) (Stothers & Chin 1991, Chiose & Summa 1970, Iben 1966)

ν Cep (CNO_{LTE}: solar)

… atmosphere parameters (T_{eff} vs. log g)



Positions of the both two supergiants and some comparison stars in the T_{eff} vs. log g plane.

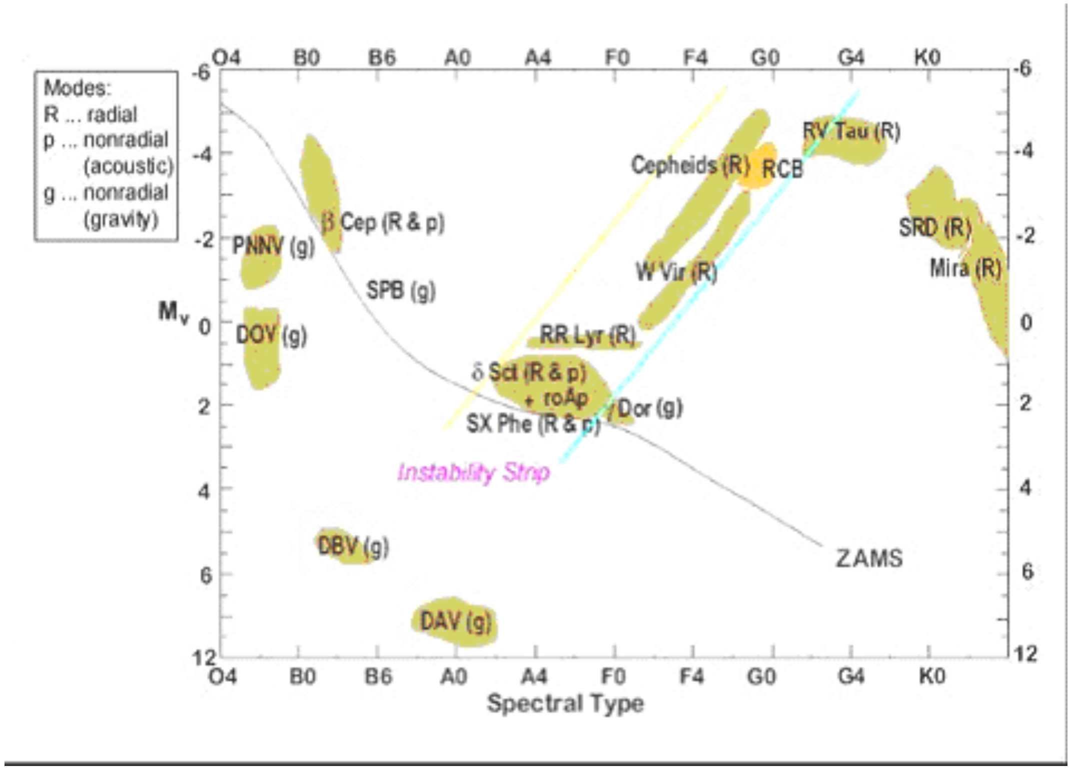


Locations of the two stars on the theoretical evolutionary paths of Schaller et al. (1992)

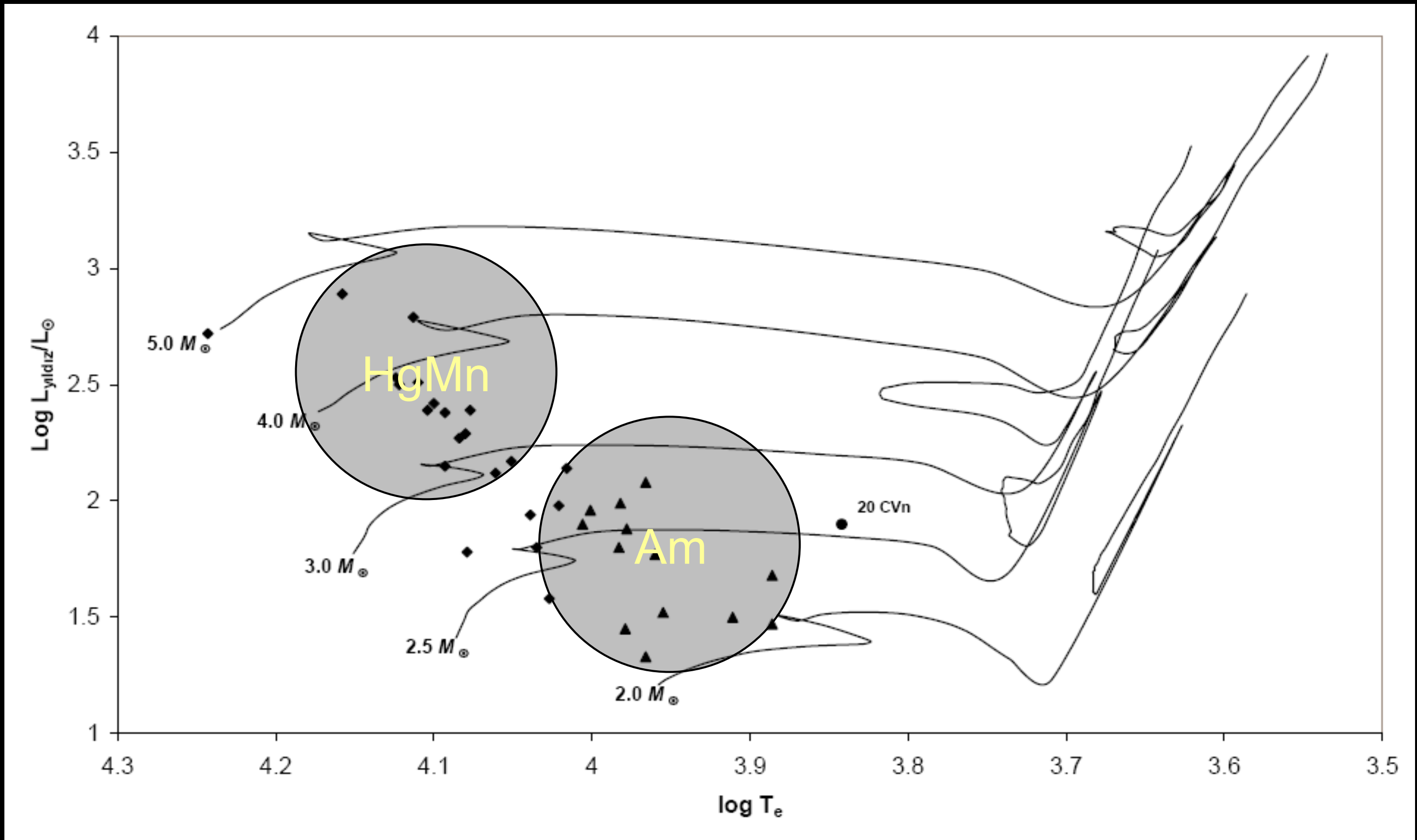
Their parents
Lac OB1 : 16-25x10^6 year (Blaauw 1958)
Cep OB2 : 7-3x10^6 year, Simon & Greve 1976)

Another sample star : **20 CVn** is in the region of classical Cepheid instability strip in the HR diagram. The stars in the region exhibit variety about the chemical abundances. The instability strip is a very suitable laboratory of asteroseismology (Breger 2000). Asteroseismology, an analogon to geoseismology, makes it possible to "look" into the stellar interior by measuring the oscillation of the star.

An accurate atmosphere parameter obtained from detailed spectral analysis is also important to determine pulsation constant which is valuable parameter of asteroseismology.



√ The stars HgMn (♦) & Am (▲) and 20 CVn from DAO spectra and using the same technique (Adelman and collobrators), locations on the Schaller et al. (1992)'s theoretical evolutionary paths.



The abundance analysis is also used to test the stellar evolutionary status

For example, Adelman et al. (2003) found that the coolest HgMn stars evolved into the hottest Am stars. Studies of elements other than Hg show that the elemental abundance values are similar across the supposed HgMn-Am star boundary. Adelman & Unsuree (2007) found near spectral type A0 that the normal and Am star abundances showed not clear break. Further work in this regard is needed in the middle A stars where there are few normal sharp-lined A stars and near spectral type F0 where most normal stars are also delta Scuti stars. The few analyses of the later stars are consistant with results similar to that of Adelman & Unsuree (2007), but more stars are needed to confirm this interpretation.

The time-scale for the peculiarities to be developed remain unclear since the results of studies of evolutionary status of chemically peculiar stars of different type show somewhat contradictory results (Gonzalez, Hubrig, Castelli, 2010).

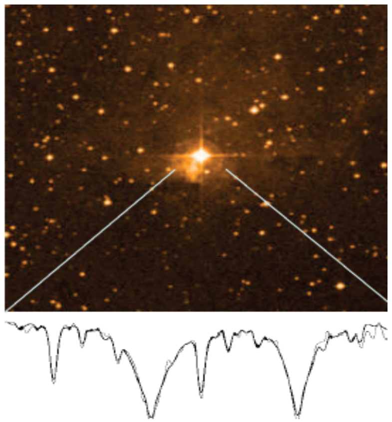
Comment about this part :

As some stars have atmospheric abundances close to those of the sun, codes such as ATLAS9 use scaled solar compositions to precompute the line and continuum opacities in the form of opacity distribution functions. ATLAS12 uses opacity sampling to permit one to arbitrarily compute a model atmospheres with an arbitrary compositon.

With the synthetic spectra and with improved atomic data using much larger wavelength coverage (~3050-10000Å) the atmosphere analyses clarify the nature of the stellar atmosphere.

Introduction to TUG RTT150 CES

1.5-m Russian-Turkish Telescope
at the Turkish National Observatory
in Antalya where is at the south of Turkey.



www.tug.tubitak.gov.tr

AIMS OF OUR INVESTIGATION (Yüce, Adelman, & Gürol)

I- Goals concerning the quality of the spectra: It provides some information about the characteristic of TUG spectrograms :

a. Compare several stars with those of Drs. Saul J. Adelman and Austin F. Gulliver are observing to high S/N. We want to get data with S/N = 250+. Measurements show the relations of the equivalent width taken with the Coude Echellé Spectrometer RTT150 and with the DAO coude spectrograph.

b. Determine the instrumental line profile from the ThAr arc spectrum.

c. Determine how long one can observe and still be able to remove cosmic rays successfully from the raw spectra. The suggestion by that this time is about 30 minutes is plausible.

d. Want to see how large S/N can be reached by coadding the spectra. Gulliver advised Dr. Olga Pintado (CASLEO) concerning doing this in raw space.

II- Scientific case : Elemental abundance analyses of Normal A, F and Am stars

We should know the characteristic of RTT150-CES;

1) S/N variations and spectral line profile characteristics at the red, blue and center of orders,

2) S/N variations with single spectrum and coadded spectra of star,

3) Characteristics of the telluric lines for orders,

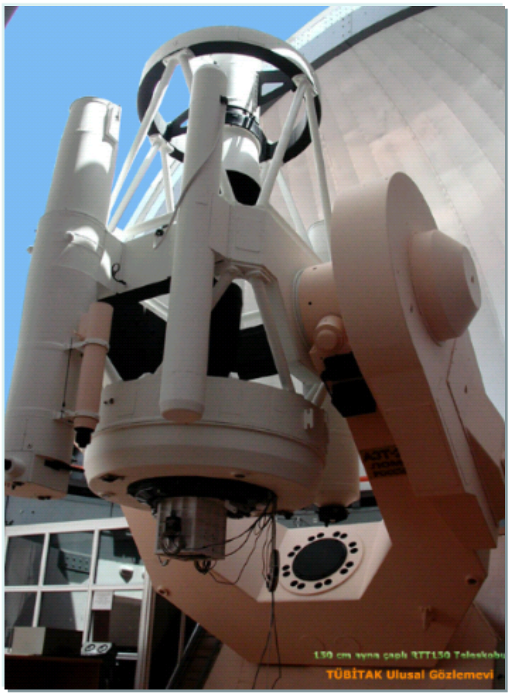
4) The equivalent width measurement comparison of weak and strong metal lines with respect to those published in literature,

5) Radial velocity variations within CES orders,

6) Spectral quality: the results of our experiments in taking multiple bias, flat & star exposures.

Observations – RTT150 CES

The RTT150 CES is operating with R = 40000 resolution and nowly 2k x 2k Russian made liquid nitrogen cooled CCD. The spectral range of **λλ3800-10000Å** is covered in one frame. Echelle spectral orders overlap in wavelength in the 3800- 8000 Å region with small gaps in 8000-10000 Å region. (www.tug.tubitak.gov.tr)



chosen stars: I-V luminosity class
0-6 mag.

General information from our first observation run.

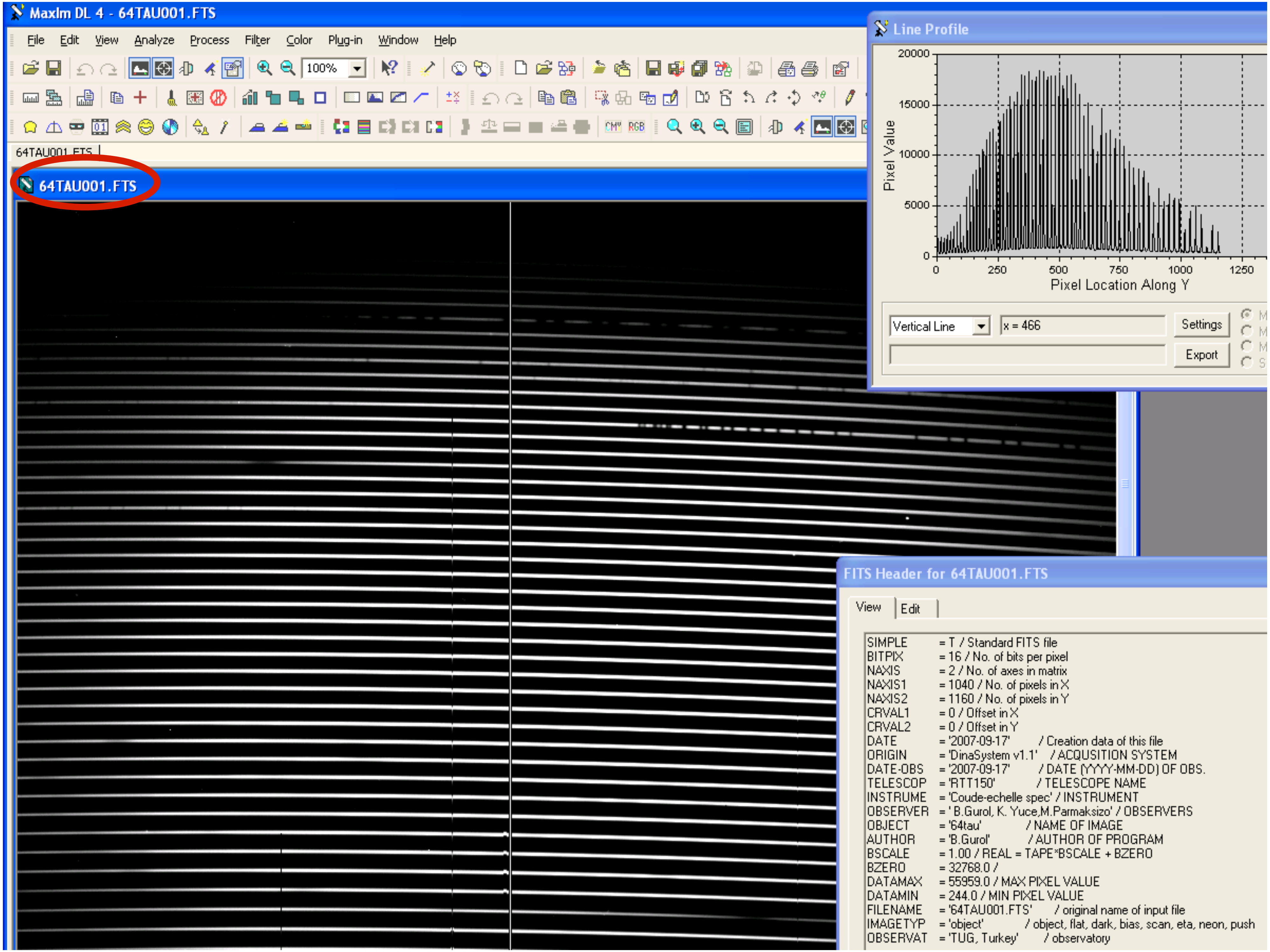
star	m_v	max S/N	SpT
Vega	0.03	Co500-600	A0 V
Deneb	1.3	Co500-650	A2 Iae
γ Gem	1.9	140, 250	A0 IV
HR 4128	2.0	350, 450	G9 II-III
38 Tau	3.9	250, 435	A0.5 Va
ν Cep	4.3	220, Co375	A2 Iab
4 Lac	4.5	325	B9 Iab
64 Tau	4.8	225	A7 V
29 Psc	5.1	180	B7 III-IV
HR6455	5.3	160	A3 III
53 Cas	5.6	320	B8 Ib
42 Cyg	5.9	200	A1 Ib
HR 7545	5.9	240	A2 III
HD 207673	6.4	140	A2 Ib

Observer: Kutluay Yüce

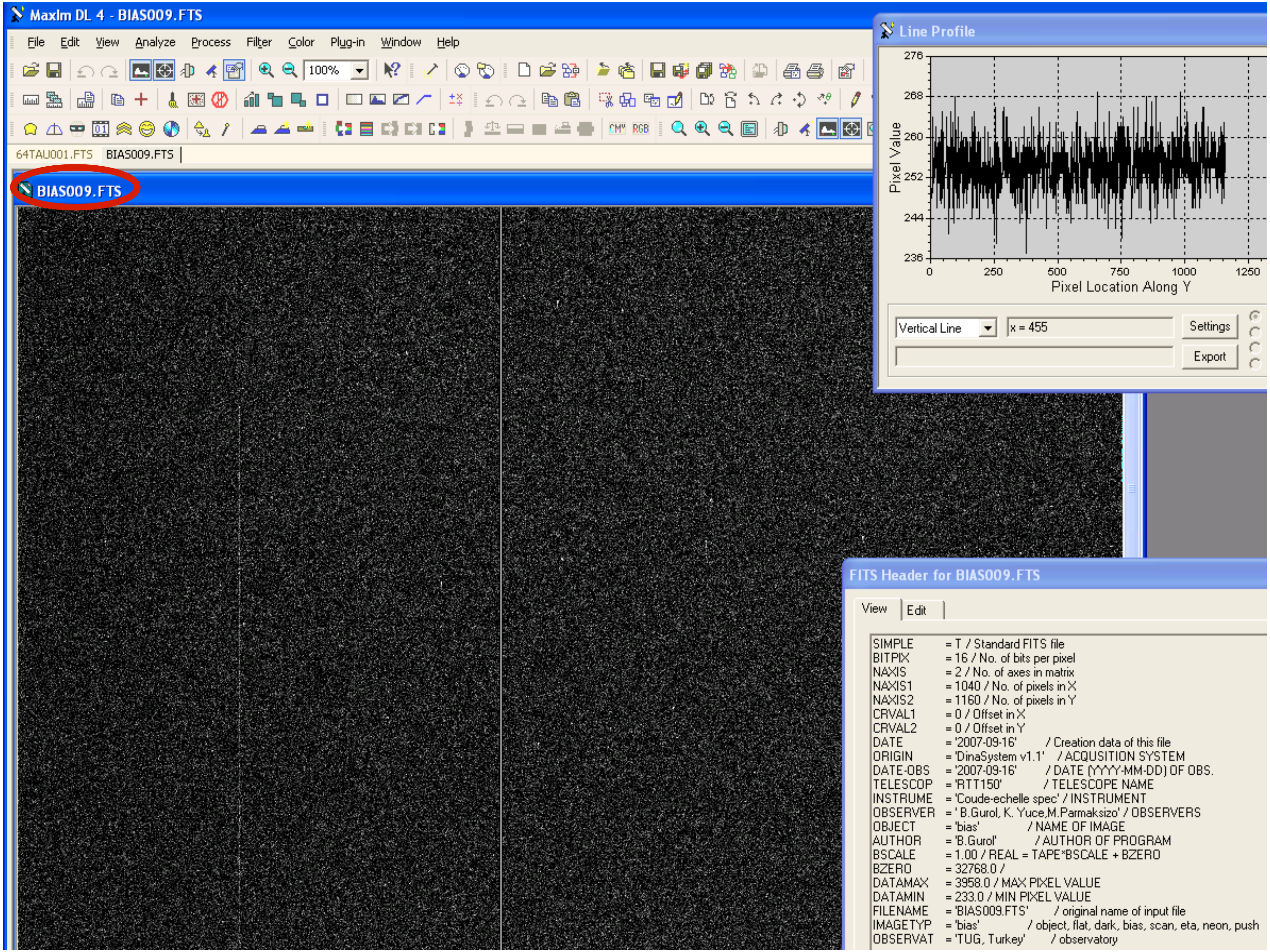
14 April 2010

Reduction : IRAF (Image Reduction and Analysis Facility) program

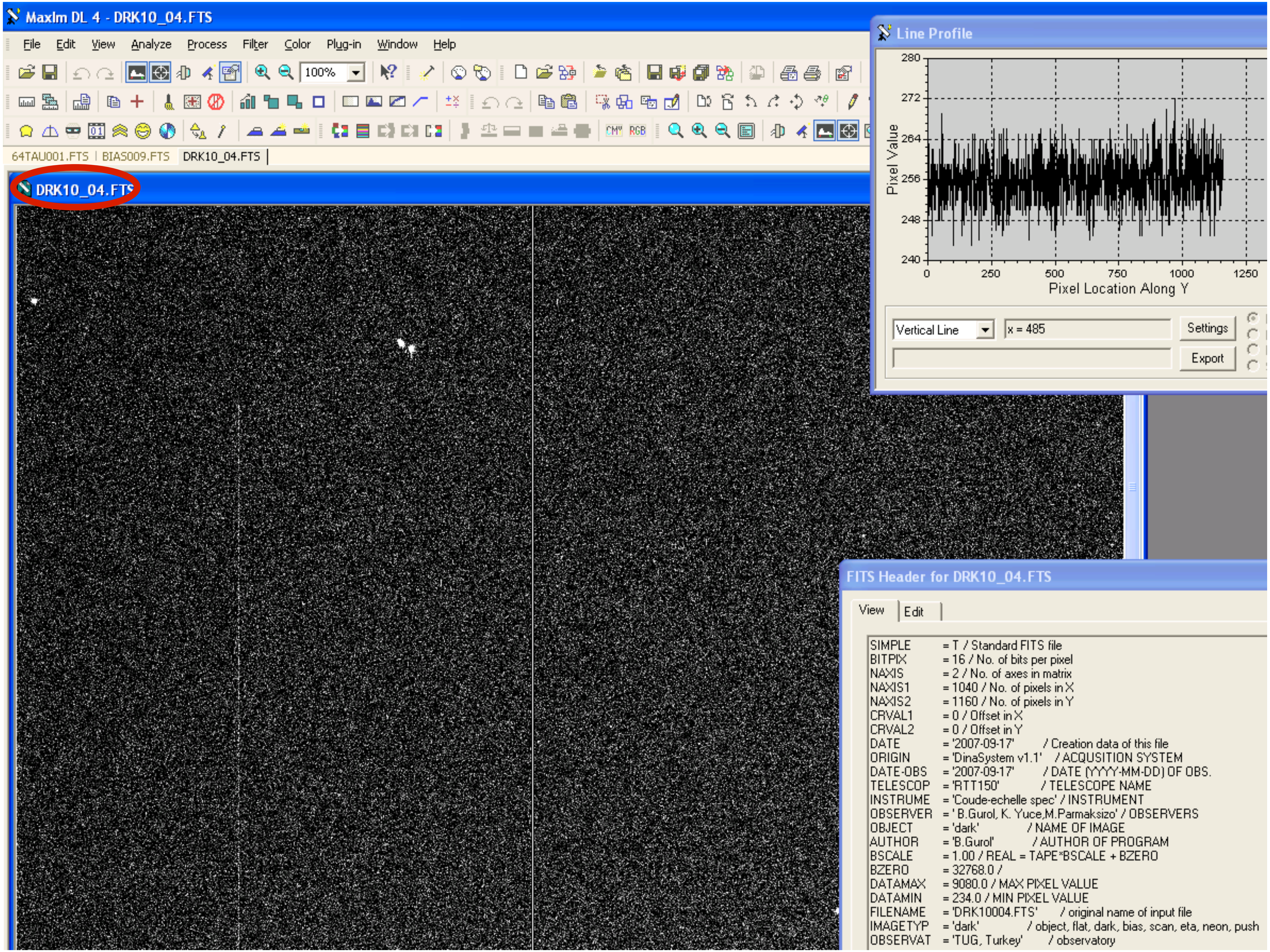
The spectral images were corrected for bias, dark, and flat field effects. After this correction we extract 1-d spectra of the targets and the Th Ar arcs using IRAF routines. The wavelength calibrations had at most rms ≈ 0.004 [unit in Å]. The wavelengths of the stellar spectra were corrected for the motions of the Earth about the solar center.



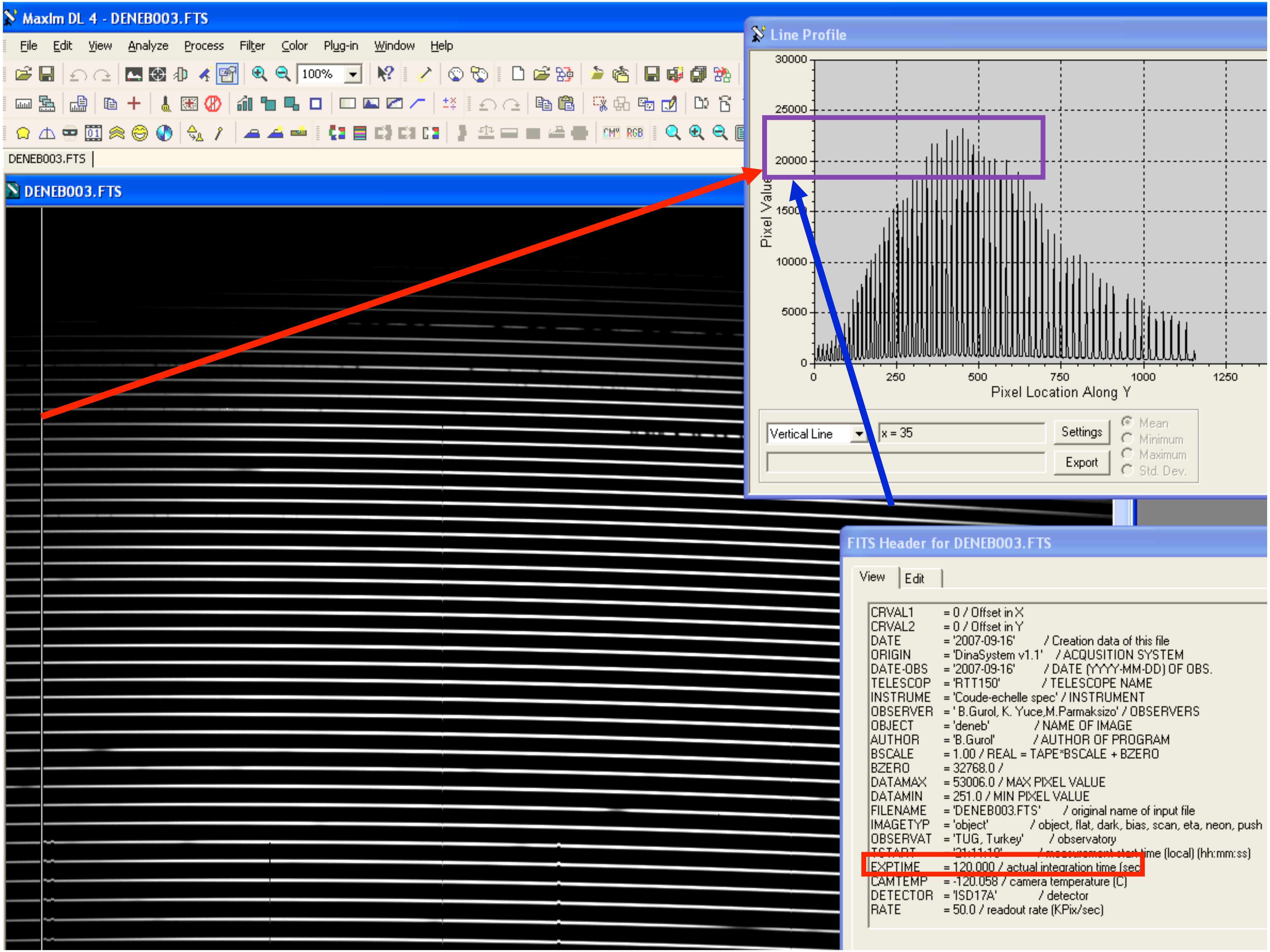
MaxIm DL 4 - 64TAU001.FTS
File Edit View Analyze Process Filter Color Plug-in Window Help
100%
64TAU001.FTS
64TAU001.FTS
Line Profile
Pixel Value
20000
15000
10000
5000
0
0 250 500 750 1000 1250
Pixel Location Along Y
Vertical Line
x = 466
Settings
Export
FITS Header for 64TAU001.FTS
View
Edit
SIMPLE = T / Standard FITS file
BITPIX = 16 / No. of bits per pixel
NAXIS = 2 / No. of axes in matrix
NAXIS1 = 1040 / No. of pixels in X
NAXIS2 = 1160 / No. of pixels in Y
CRVAL1 = 0 / Offset in X
CRVAL2 = 0 / Offset in Y
DATE = '2007-09-17' / Creation data of this file
ORIGIN = 'DinaSystem v1.1' / ACQUSITION SYSTEM
DATE-OBS = '2007-09-17' / DATE (YYYY-MM-DD) OF OBS.
TELESCOP = 'RTT150' / TELESCOPE NAME
INSTRUME = 'Coude-echelle spec' / INSTRUMENT
OBSERVER = ' B.Gurol, K. Yuce,M.Parmaksizo' / OBSERVERS
OBJECT = '64tau' / NAME OF IMAGE
AUTHOR = 'B.Gurol' / AUTHOR OF PROGRAM
BSCALE = 1.00 / REAL = TAPE*BSCALE + BZERO
BZERO = 32768.0 /
DATAMAX = 55959.0 / MAX PIXEL VALUE
DATAMIN = 244.0 / MIN PIXEL VALUE
FILENAME = '64TAU001.FTS' / original name of input file
IMAGETYP = 'object' / object, flat, dark, bias, scan, eta, neon, push
OBSERVAT = 'TUG, Turkey' / observatory

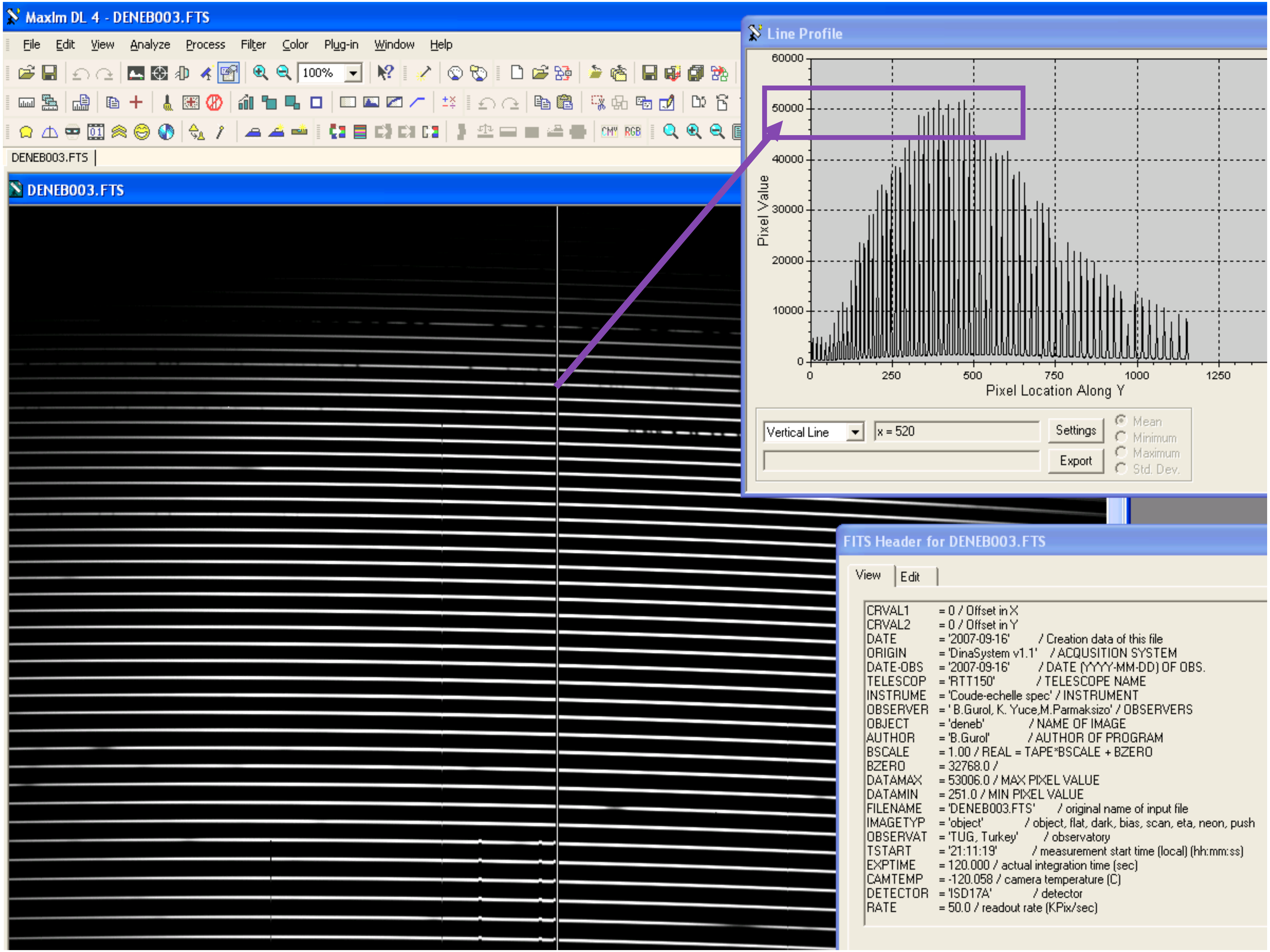


MaxIm DL 4 - BIAS009.FTS
File Edit View Analyze Process Filter Color Plug-in Window Help
100%
64TAU001.FTS BIAS009.FTS
BIAS009.FTS
Line Profile
Pixel Value
276
268
260
252
244
236
0 250 500 750 1000 1250
Pixel Location Along Y
Vertical Line
x = 455
Settings
Export
FITS Header for BIAS009.FTS
View Edit
SIMPLE = T / Standard FITS file
BITPIX = 16 / No. of bits per pixel
NAXIS = 2 / No. of axes in matrix
NAXIS1 = 1040 / No. of pixels in X
NAXIS2 = 1160 / No. of pixels in Y
CRVAL1 = 0 / Offset in X
CRVAL2 = 0 / Offset in Y
DATE = '2007-09-16' / Creation data of this file
ORIGIN = 'DinaSystem v1.1' / ACQUSITION SYSTEM
DATE-OBS = '2007-09-16' / DATE (YYYY-MM-DD) OF OBS.
TELESCOP = 'RTT150' / TELESCOPE NAME
INSTRUME = 'Coude-echelle spec' / INSTRUMENT
OBSERVER = ' B.Gurol, K. Yuce,M.Parmaksizo' / OBSERVERS
OBJECT = 'bias' / NAME OF IMAGE
AUTHOR = 'B.Gurol' / AUTHOR OF PROGRAM
BSCALE = 1.00 / REAL = TAPE*BSCALE + BZERO
BZERO = 32768.0 /
DATAMAX = 3958.0 / MAX PIXEL VALUE
DATAMIN = 233.0 / MIN PIXEL VALUE
FILENAME = 'BIAS009.FTS' / original name of input file
IMAGETYP = 'bias' / object, flat, dark, bias, scan, eta, neon, push
OBSERVAT = 'TUG, Turkey' / observatory



MaxIm DL 4 - DRK10_04.FTS
File Edit View Analyze Process Filter Color Plug-in Window Help
100%
64TAU001.FTS
BIAS009.FTS
DRK10_04.FTS
DRK10_04.FTS
Line Profile
280
272
264
256
248
240
Pixel Value
0
250
500
750
1000
1250
Pixel Location Along Y
Vertical Line
x = 485
Settings
Export
FITS Header for DRK10_04.FTS
View
Edit
SIMPLE = T / Standard FITS file
BITPIX = 16 / No. of bits per pixel
NAXIS = 2 / No. of axes in matrix
NAXIS1 = 1040 / No. of pixels in X
NAXIS2 = 1160 / No. of pixels in Y
CRVAL1 = 0 / Offset in X
CRVAL2 = 0 / Offset in Y
DATE = '2007-09-17' / Creation data of this file
ORIGIN = 'DinaSystem v1.1' / ACQUSITION SYSTEM
DATE-OBS = '2007-09-17' / DATE (YYYY-MM-DD) OF OBS.
TELESCOP = 'RTT150' / TELESCOPE NAME
INSTRUME = 'Coude-echelle spec' / INSTRUMENT
OBSERVER = ' B.Gurol, K. Yuce,M.Parmaksizo' / OBSERVERS
OBJECT = 'dark' / NAME OF IMAGE
AUTHOR = 'B.Gurol' / AUTHOR OF PROGRAM
BSCALE = 1.00 / REAL = TAPE*BSCALE + BZERO
BZERO = 32768.0 /
DATAMAX = 9080.0 / MAX PIXEL VALUE
DATAMIN = 234.0 / MIN PIXEL VALUE
FILENAME = 'DRK10004.FTS' / original name of input file
IMAGETYP = 'dark' / object, flat, dark, bias, scan, eta, neon, push
OBSERVAT = 'TUG, Turkey' / observatory


MaxIm DL 4 - DENEB003.FTS
File Edit View Analyze Process Filter Color Plug-in Window Help
100%
DENEB003.FTS
DENEB003.FTS
Line Profile
30000
25000
20000
15000
10000
5000
0
Pixel Value
0 250 500 750 1000 1250
Pixel Location Along Y
Vertical Line
x = 35
Settings
Export
Mean
Minimum
Maximum
Std. Dev.
FITS Header for DENEB003.FTS
View
Edit
CRVAL1 = 0 / Offset in X
CRVAL2 = 0 / Offset in Y
DATE = '2007-09-16' / Creation data of this file
ORIGIN = 'DinaSystem v1.1' / ACQUSITION SYSTEM
DATE-OBS = '2007-09-16' / DATE (YYYY-MM-DD) OF OBS.
TELESCOP = 'RTT150' / TELESCOPE NAME
INSTRUME = 'Coude-echelle spec' / INSTRUMENT
OBSERVER = ' B.Gurol, K. Yuce,M.Parmaksizo' / OBSERVERS
OBJECT = 'deneb' / NAME OF IMAGE
AUTHOR = 'B.Gurol' / AUTHOR OF PROGRAM
BSCALE = 1.00 / REAL = TAPE*BSCALE + BZERO
BZERO = 32768.0 /
DATAMAX = 53006.0 / MAX PIXEL VALUE
DATAMIN = 251.0 / MIN PIXEL VALUE
FILENAME = 'DENEB003.FTS' / original name of input file
IMAGETYP = 'object' / object, flat, dark, bias, scan, eta, neon, push
OBSERVAT = 'TUG, Turkey' / observatory
(hh:mm:ss)
EXPTIME = 120.000 / actual integration time (sec
CAMTEMP = -120.058 / camera temperature (C)
DETECTOR = 'ISD17A' / detector
RATE = 50.0 / readout rate (KPix/sec)


MaxIm DL 4 - DENEB003.FTS
File Edit View Analyze Process Filter Color Plug-in Window Help
DENEB003.FTS
Line Profile
Pixel Value
Pixel Location Along Y
Vertical Line
x = 520
Settings
Export
Mean
Minimum
Maximum
Std. Dev.
FITS Header for DENEB003.FTS
View
Edit
CRVAL1 = 0 / Offset in X
CRVAL2 = 0 / Offset in Y
DATE = '2007-09-16' / Creation data of this file
ORIGIN = 'DinaSystem v1.1' / ACQUSITION SYSTEM
DATE-OBS = '2007-09-16' / DATE (YYYY-MM-DD) OF OBS.
TELESCOP = 'RTT150' / TELESCOPE NAME
INSTRUME = 'Coude-echelle spec' / INSTRUMENT
OBSERVER = ' B.Gurol, K. Yuce,M.Parmaksizo' / OBSERVERS
OBJECT = 'deneb' / NAME OF IMAGE
AUTHOR = 'B.Gurol' / AUTHOR OF PROGRAM
BSCALE = 1.00 / REAL = TAPE*BSCALE + BZERO
BZERO = 32768.0 /
DATAMAX = 53006.0 / MAX PIXEL VALUE
DATAMIN = 251.0 / MIN PIXEL VALUE
FILENAME = 'DENEB003.FTS' / original name of input file
IMAGETYP = 'object' / object, flat, dark, bias, scan, eta, neon, push
OBSERVAT = 'TUG, Turkey' / observatory
TSTART = '21:11:19' / measurement start time (local) (hh:mm:ss)
EXPTIME = 120.000 / actual integration time (sec)
CAMTEMP = -120.058 / camera temperature (C)
DETECTOR = 'ISD17A' / detector
RATE = 50.0 / readout rate (KPix/sec)

Telluric Lines

Data of orders 1-30 (**λλ5600-8700**) are affected by the telluric lines, which means that the number of stellar lines are reduced due to blending for use in chemical abundances analyses.

order	comment	order	comment	order	comment
1	-	*11*	crowded	*21*	in the red part
2	crowded	*12*	crowded	*22*	-
3	crowded	*13*	few	*23*	few
4	crowded	*14*	all	*24*	-
5	crowded	*15*	half of the order in the red	*25*	-
6	-	*16*	few	*26*	few
7	few	*17*	few	*27*	few
8	all	*18*	few	*28*	-
9	few	*19*	central of the order	*29*	few
10	few	*20*	few	*30*	few

Signal-to-Noise

The S/N was determined from the apparently cleanest regions at the continuum level, which are significiantly different in the

blue,
red, &
***central* parts of each order.**

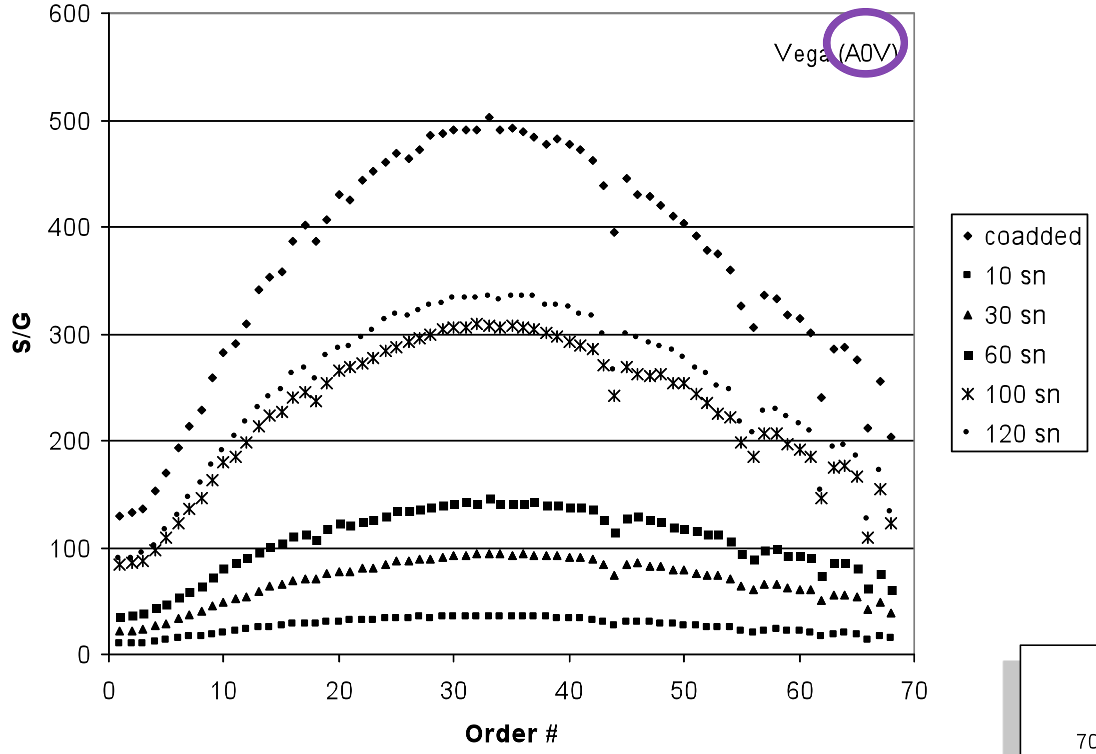
↓

- That the noise scatters are greater in both the blue and in red than in the central region reflects the lower S/N of the edges.

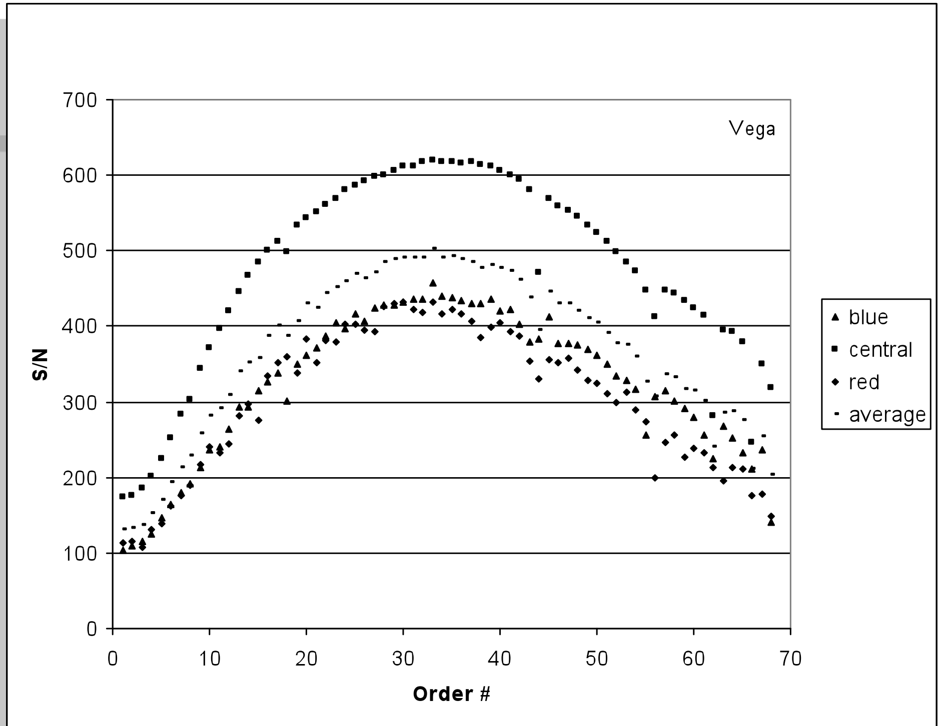
- The values are higher for the coadded spectra.

•S/N values were found 400+ for the orders 15-50 (λ4500-6500Å) from codded spectra of the bright stars Vega (0^m) and Deneb ($1^m.2$) .

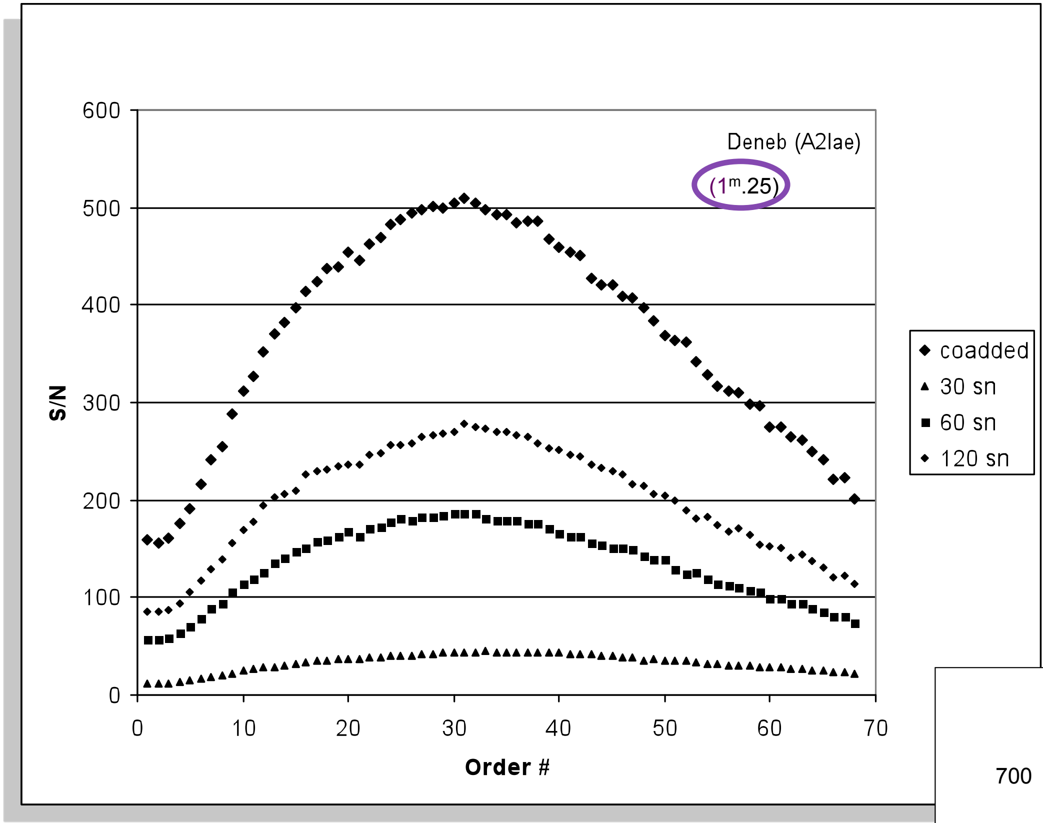
•For HD 4128, 38 Tau, ν Cep, 53 Cas, 4 Lac the values are 200+, and for other seven stars in our program they have the spectra of nearly 100+.

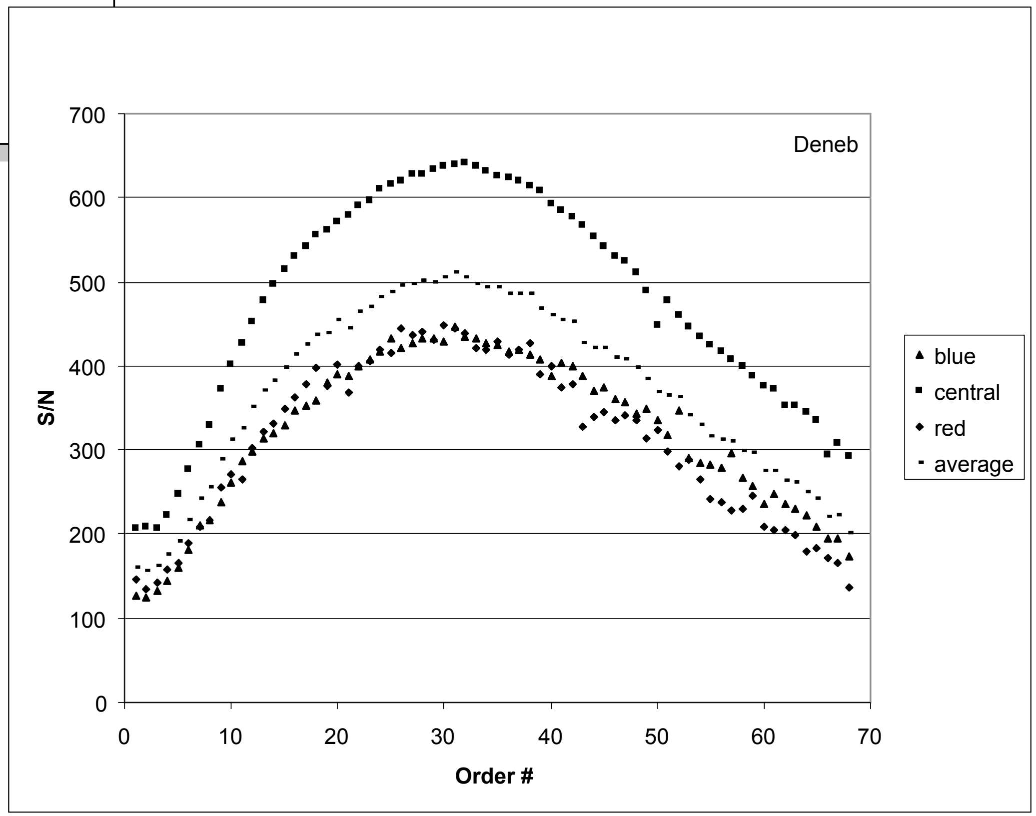


VEGA (m_v=**0**^{m}):
S/N variations from the average of the **blue**, **red**, & **central** parts of each order using several exposures and the coadded

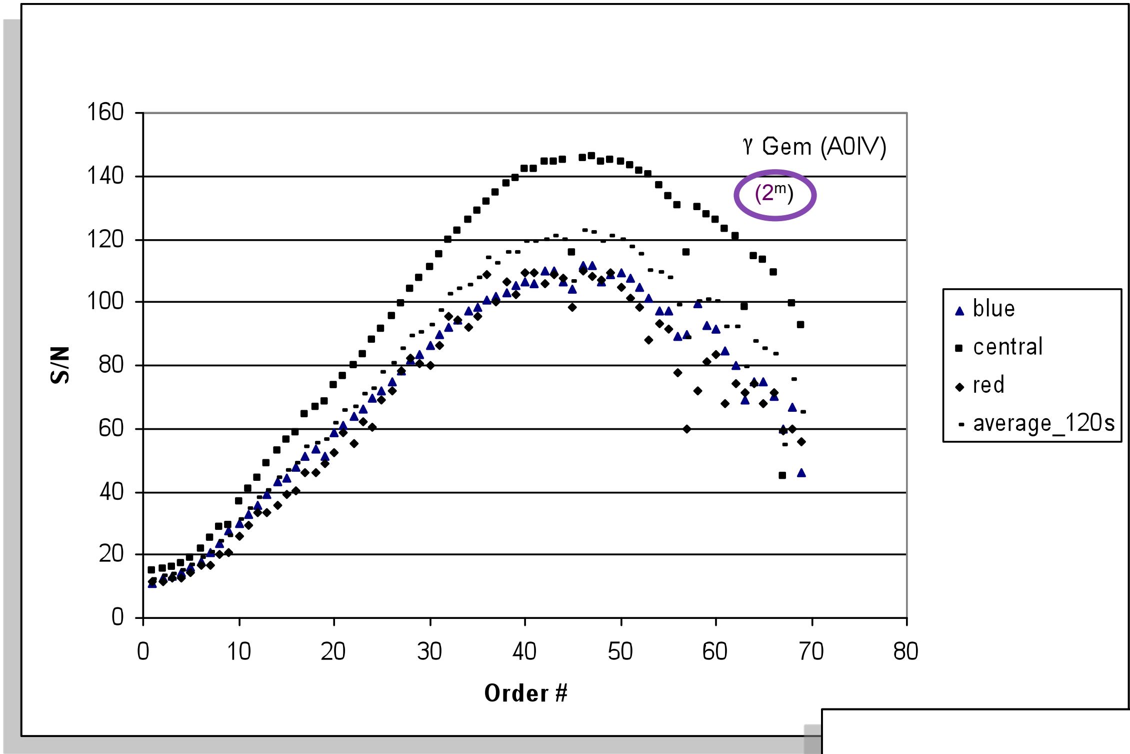


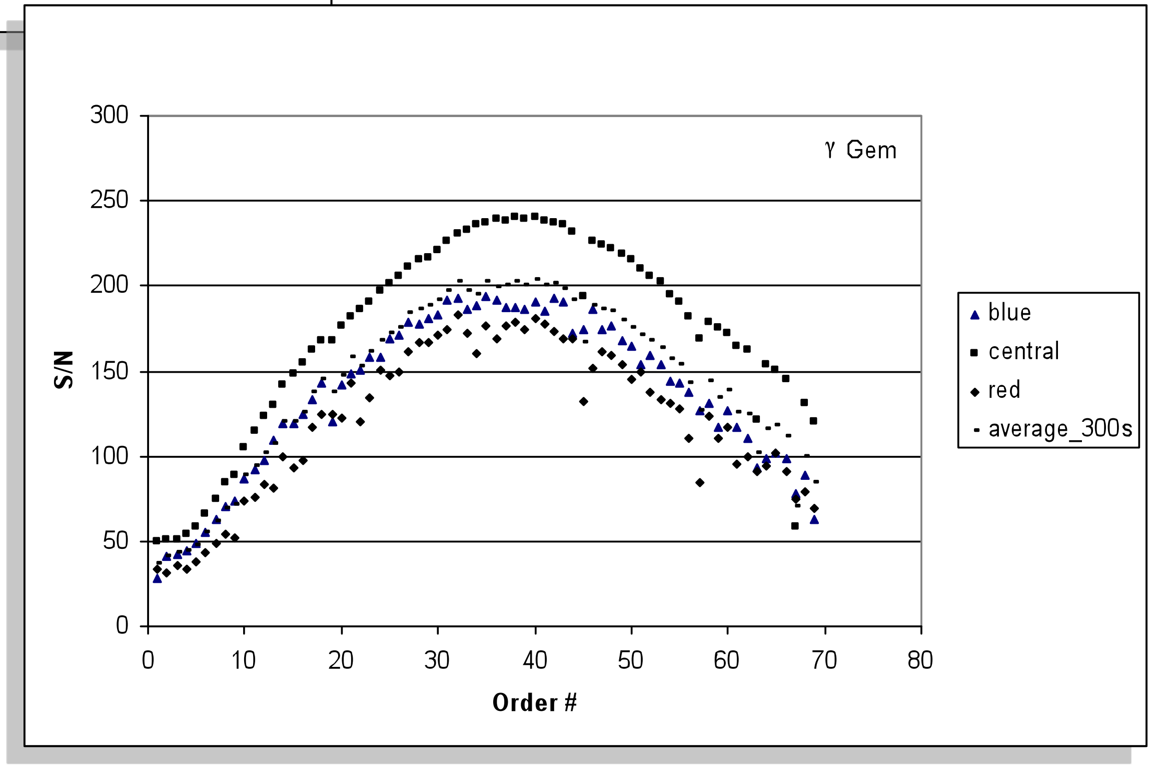
S/N variations in the **blue**, **red** & central parts of the orders for coadded spectra

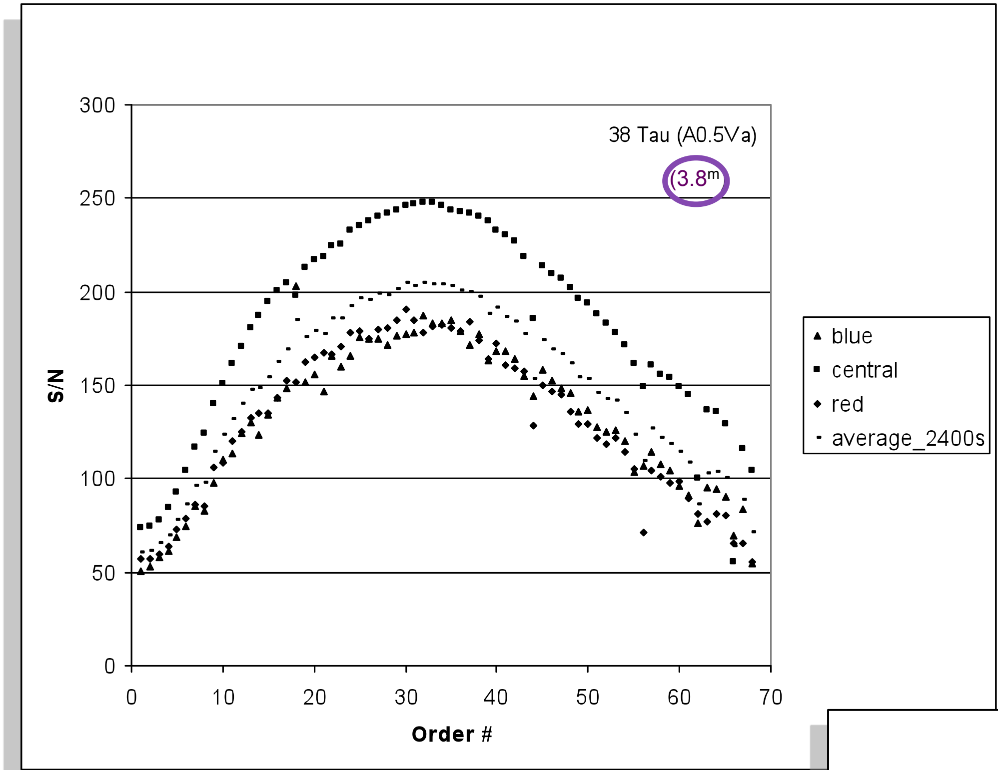


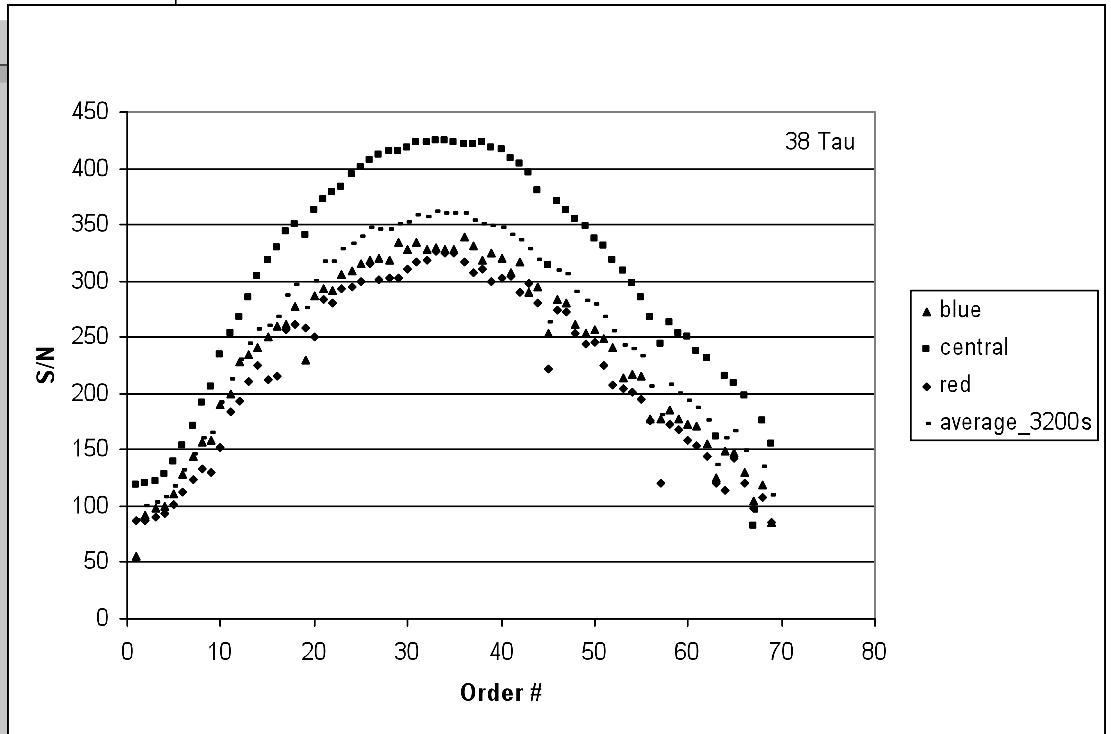


14 April 2010

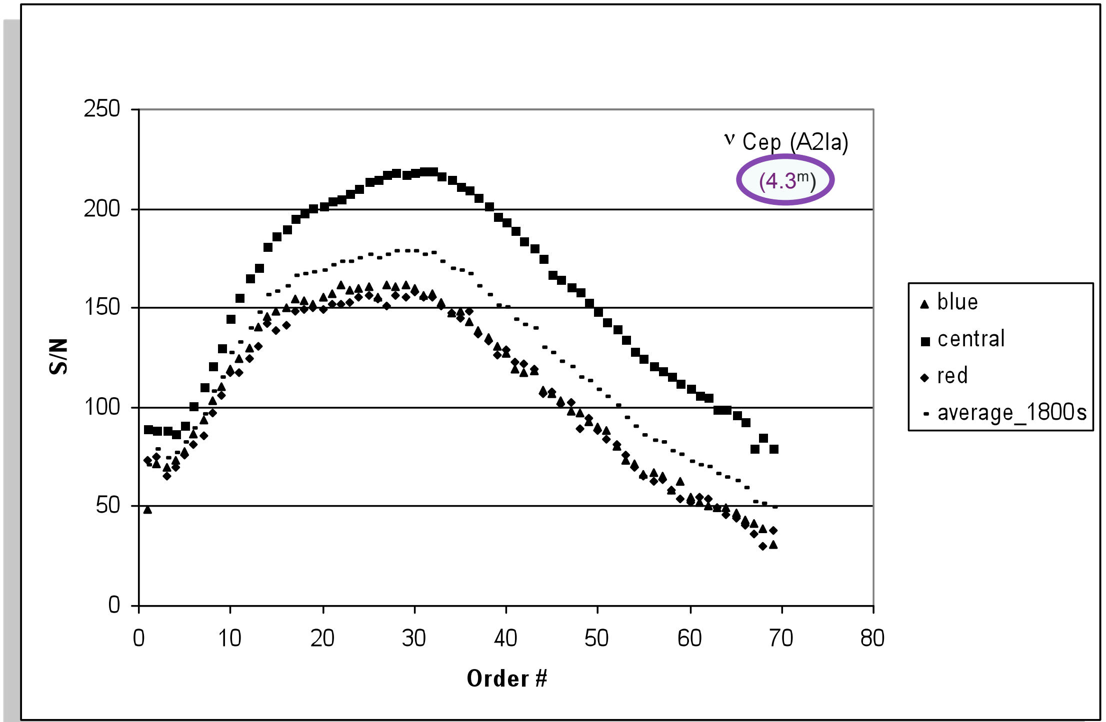

160
140
120
100
80
60
40
20
0
S/N
0
10
20
30
40
50
60
70
80
Order #
γ Gem (A0IV)
(2m)
blue
central
red
average_120s


300
250
200
150
100
50
0
S/N
0
10
20
30
40
50
60
70
80
Order #
γ Gem
blue
central
red
average_300s

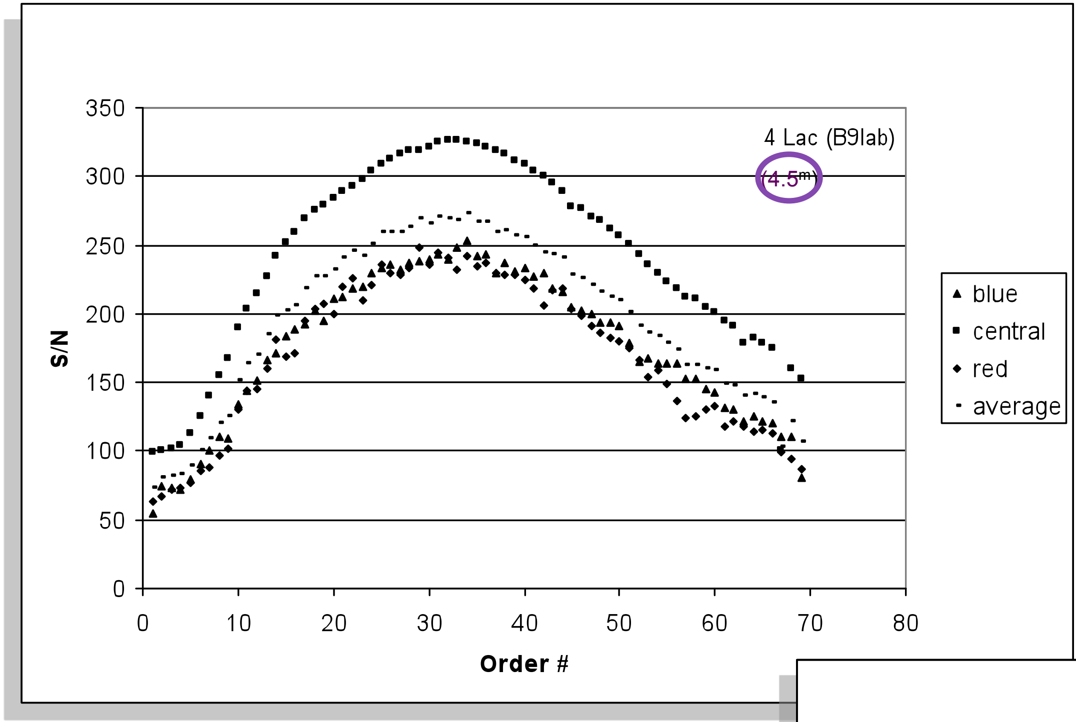




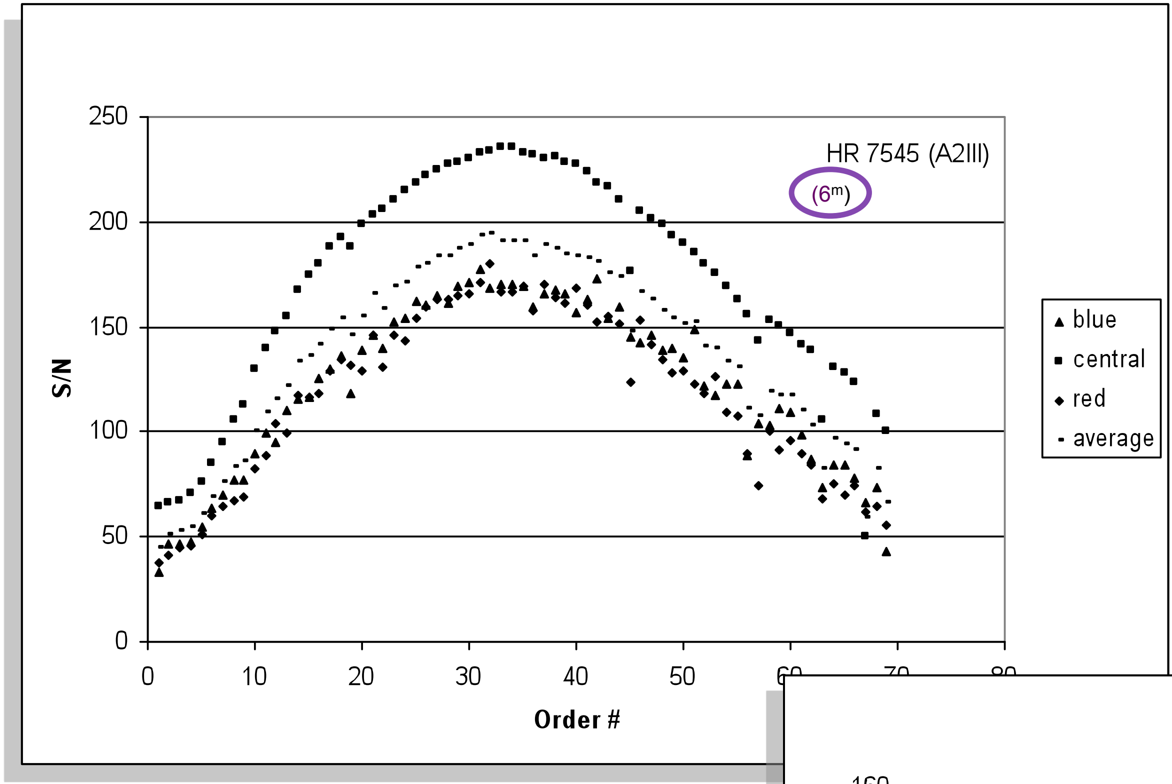
14 April 2010

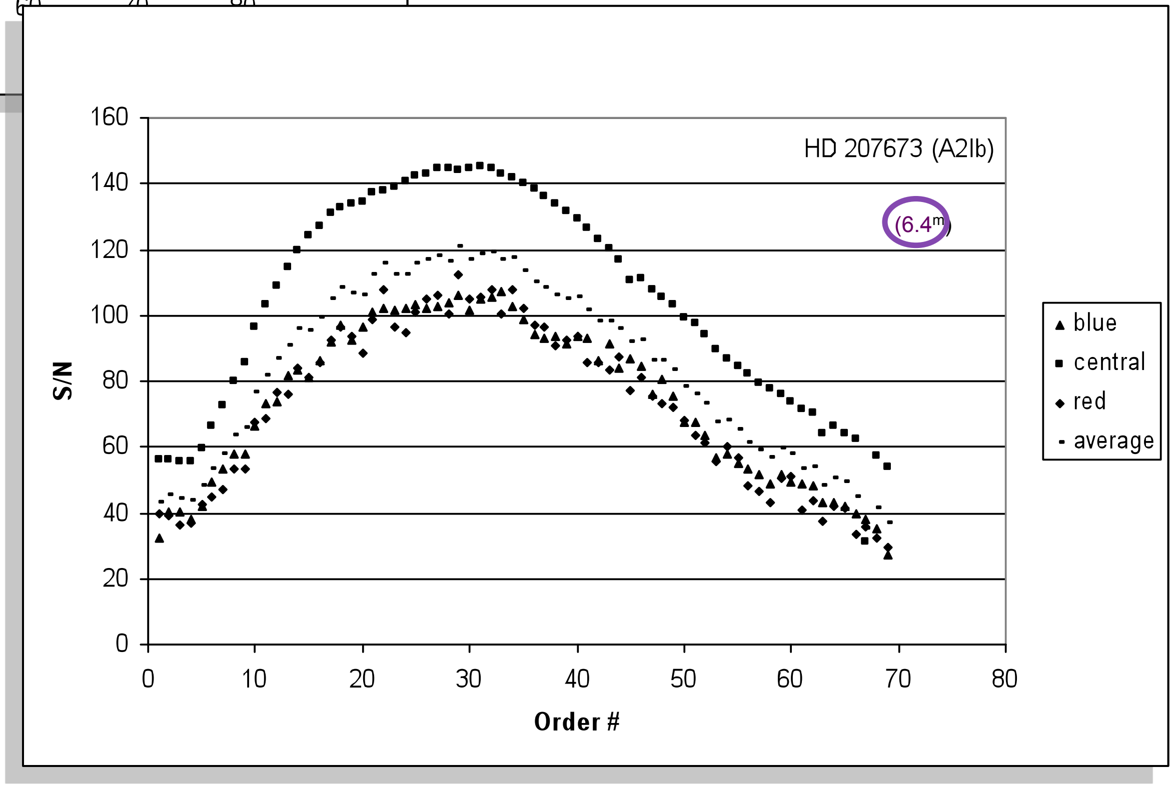


14 April 2010


4 Lac (B9Iab)
(4.5m)
S/N
Order #
blue
central
red
average

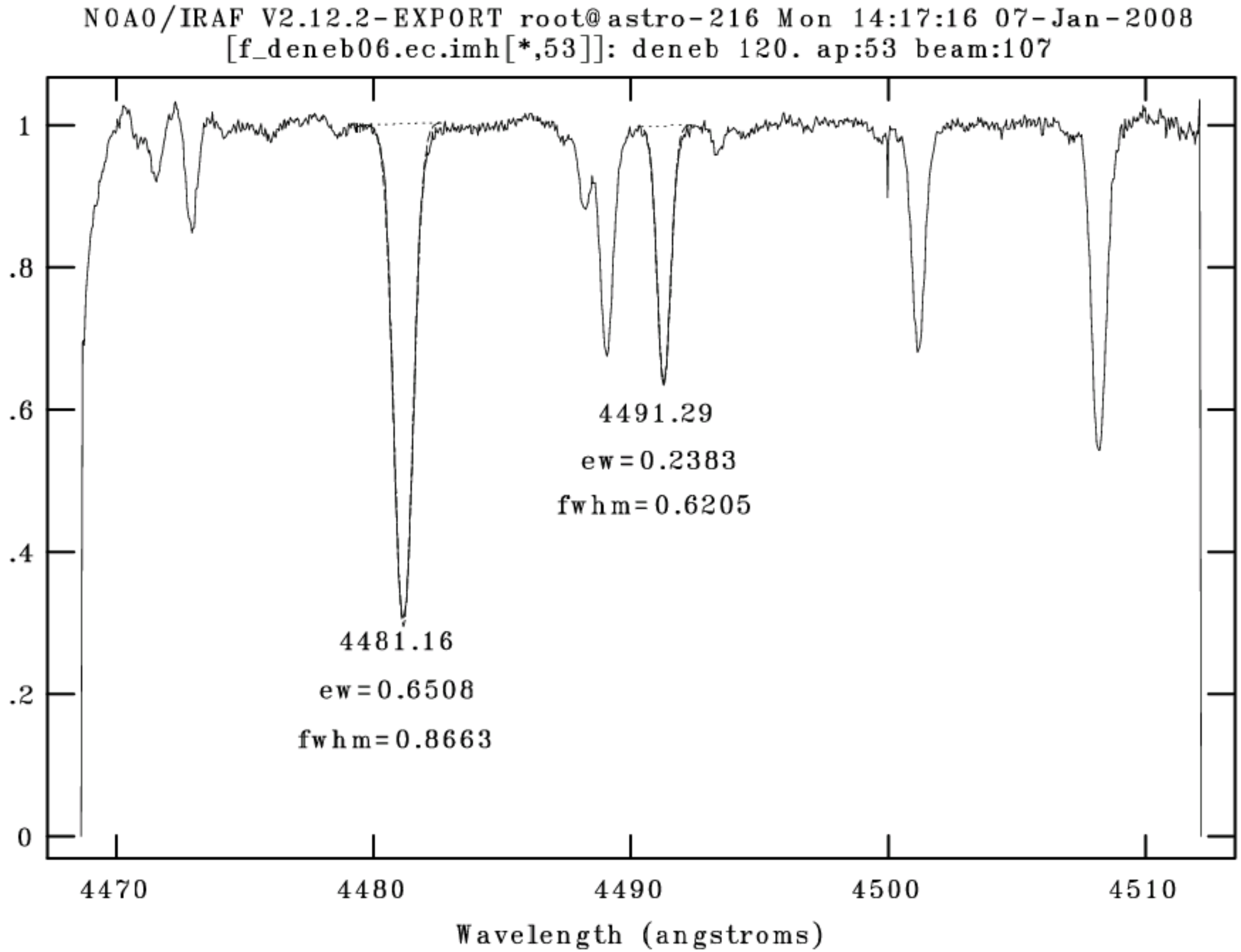

53 Cas (B8Ib)
(5.6m)
S/N
Order #
blue
central
red
average


HR 7545 (A2III)
(6m)
S/N
Order #
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
blue
central
red
average

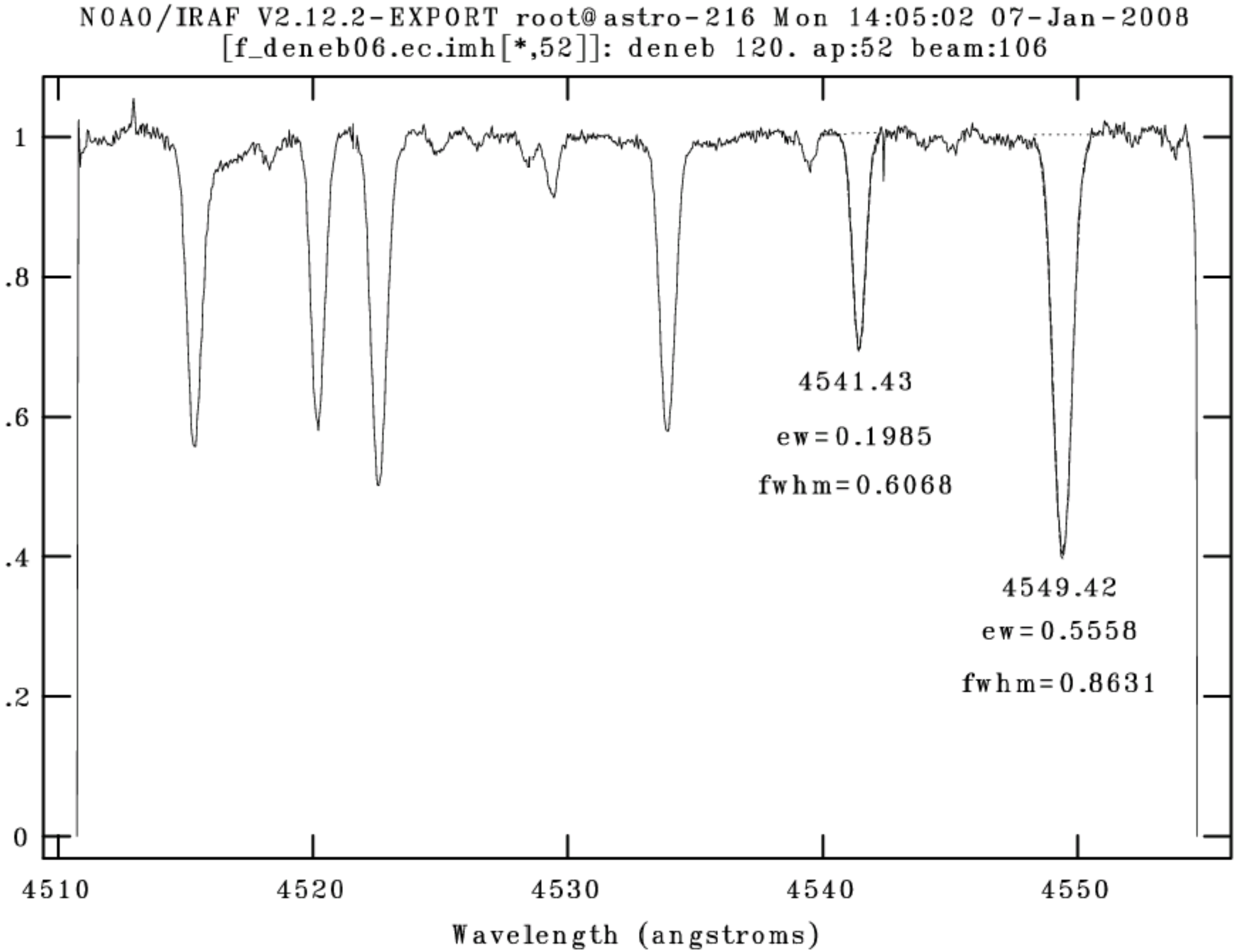

HD 207673 (A2Ib)
(6.4m)
S/N
Order #
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
blue
central
red
average

Comparison with those of high quality spectra

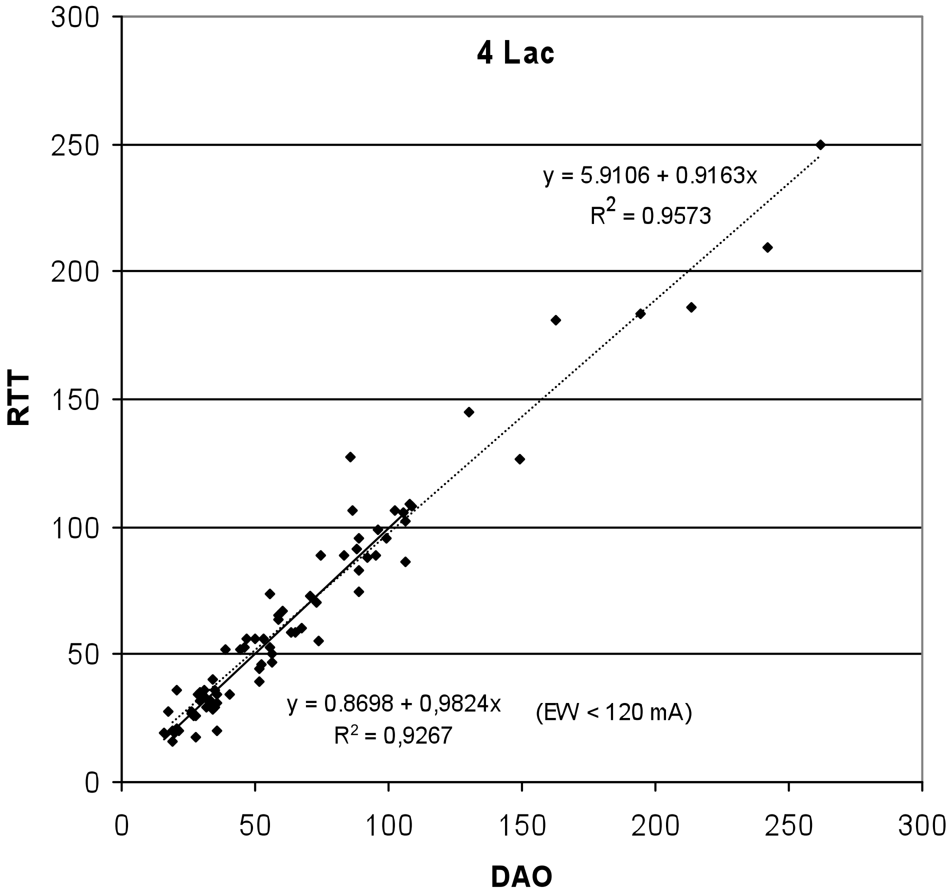
We compared the FWHM and EWs derived by IRAF program with those of 4 Lac & ν Cep (Yüce 2005)
(in the section of λλ3830-4930Å, Dominion Astrophysical Observatory, S/N 200+, REDUCE program)

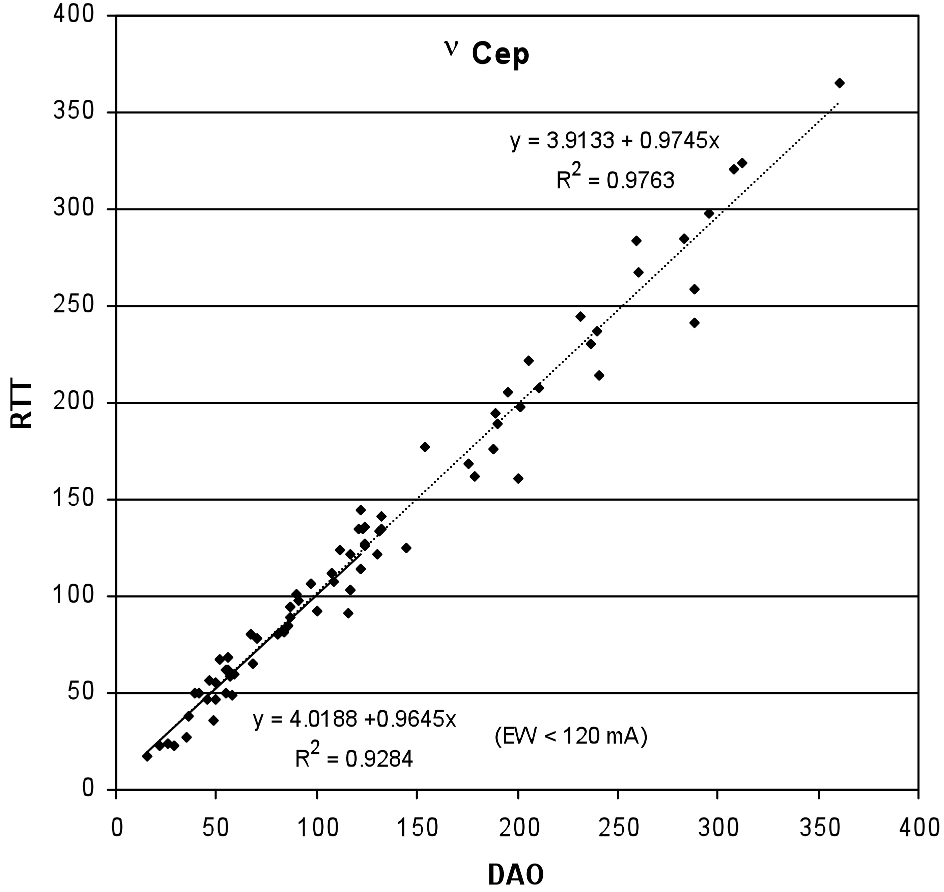


NOAO/IRAF V2.12.2-EXPORT root@astro-216 Mon 14:17:16 07-Jan-2008
[f_deneb06.ec.imh[*,53]]: deneb 120. ap:53 beam:107
4481.16
ew=0.6508
fwhm=0.8663
4491.29
ew=0.2383
fwhm=0.6205
1
.8
.6
.4
.2
0
4470
4480
4490
4500
4510
Wavelength (angstroms)


NOAO/IRAF V2.12.2-EXPORT root@astro-216 Mon 14:05:02 07-Jan-2008
[f_deneb06.ec.imh[*,52]]: deneb 120. ap:52 beam:106
4541.43
ew=0.1985
fwhm=0.6068
4549.42
ew=0.5558
fwhm=0.8631
1
.8
.6
.4
.2
0
4510
4520
4530
4540
4550
Wavelength (angstroms)

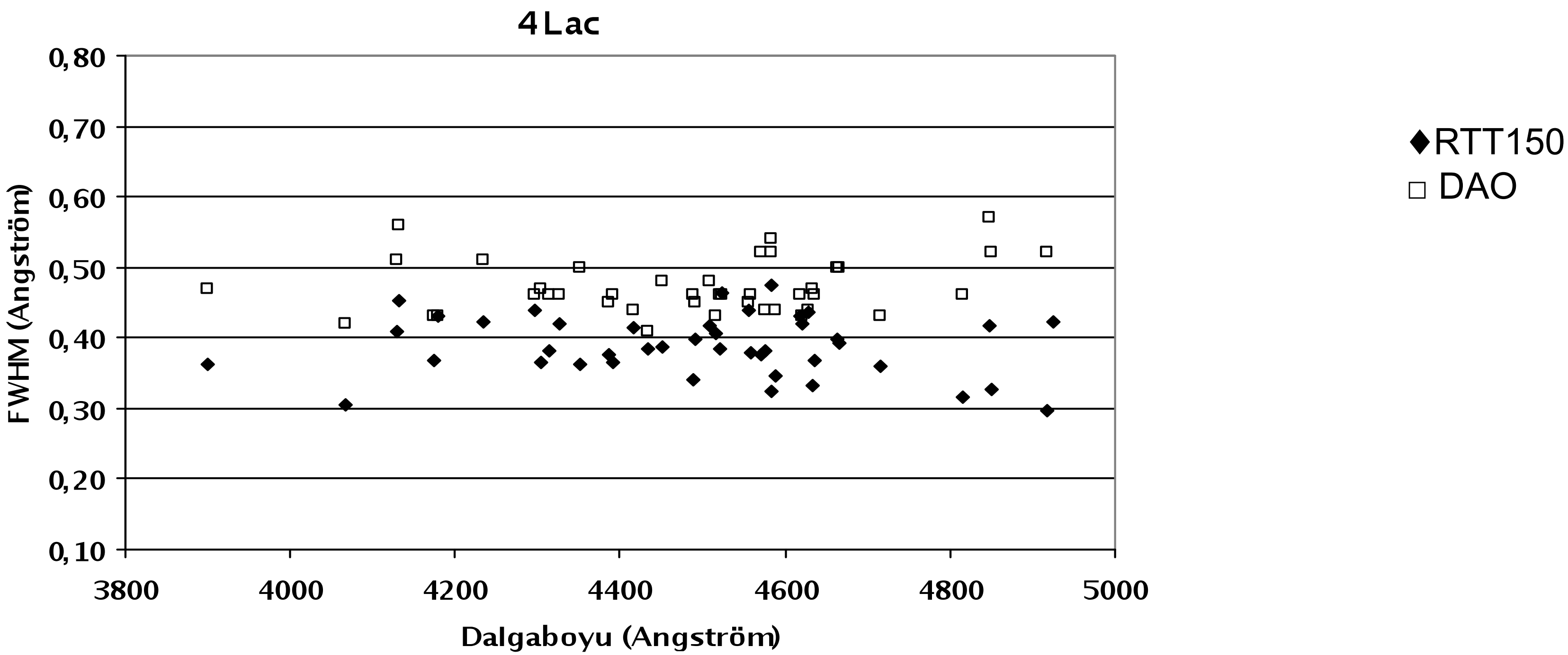
Comparison of RTT & DAO data measurements

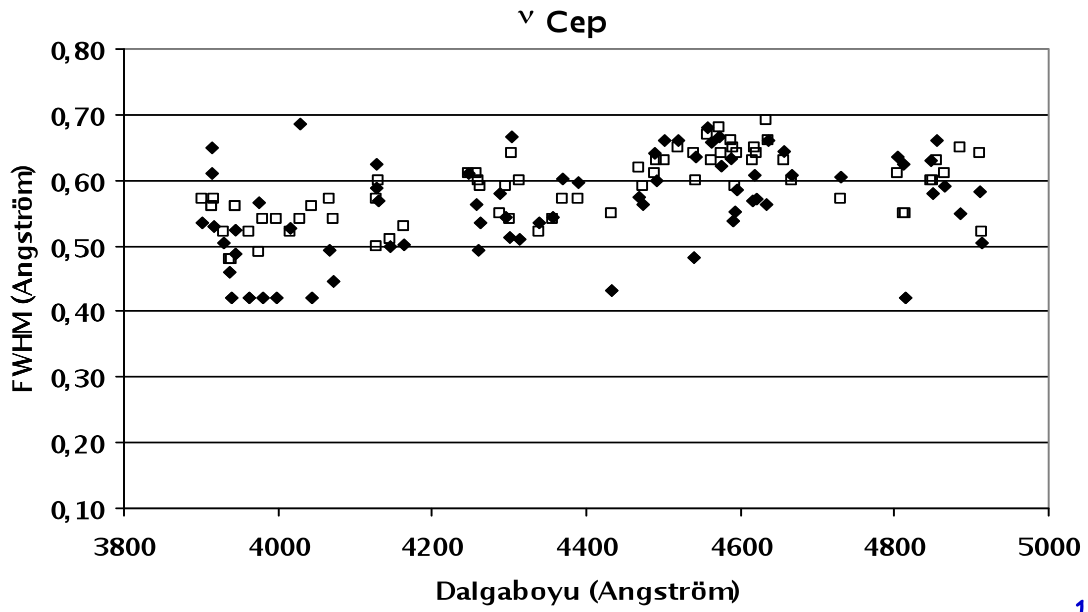




a least-sequares comparison of the EW's measured on RTT150 CES exposures.

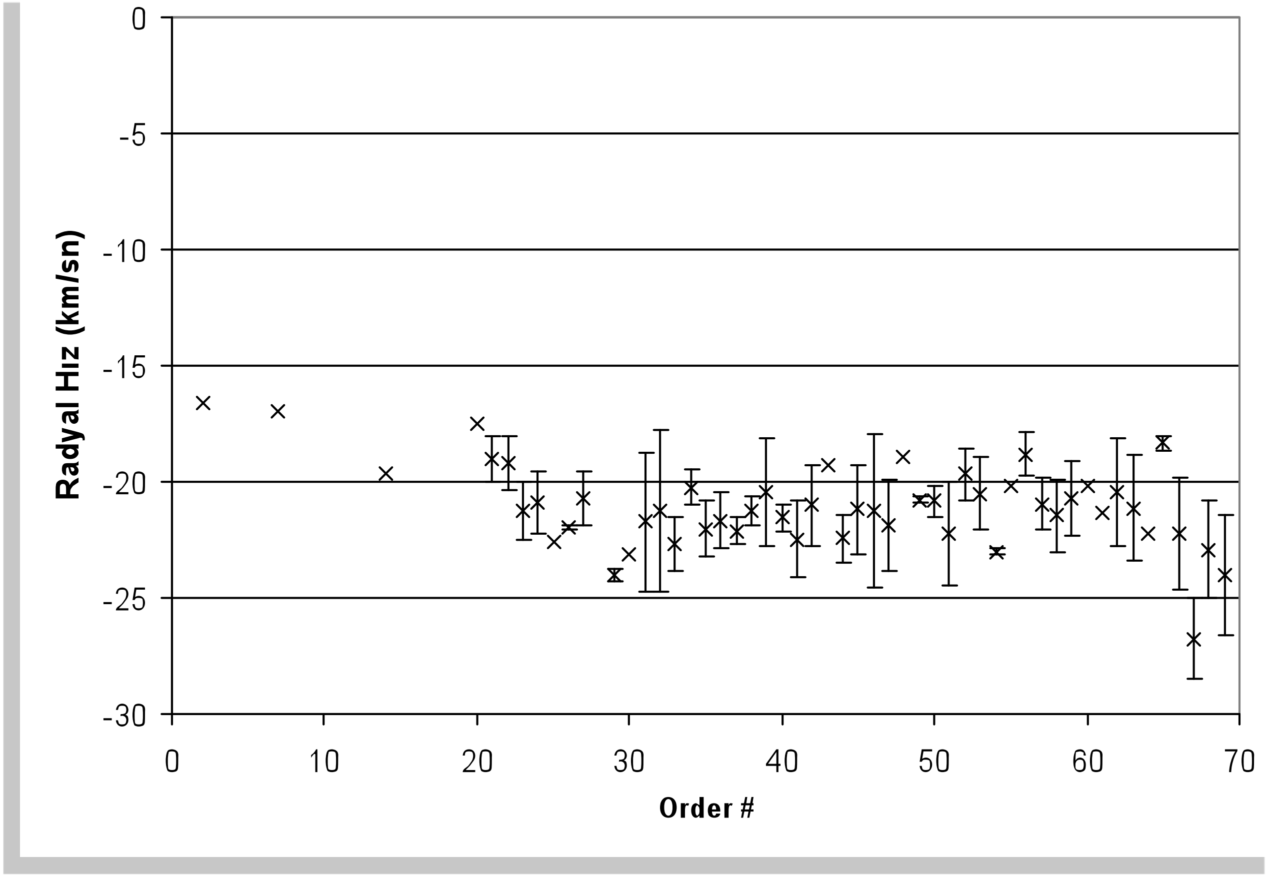
EW (RTT) = b + EW (DAO) x





14 April 2010

- For ν Cep the radial velocity variation was calculated as -21.07±1.79 kms^{-1} from our data at RTT150 CES. The radial velocity values are given between -11 and -26 kms^{-1} from DAO spectra of 1999-2000 (Yüce 2005).



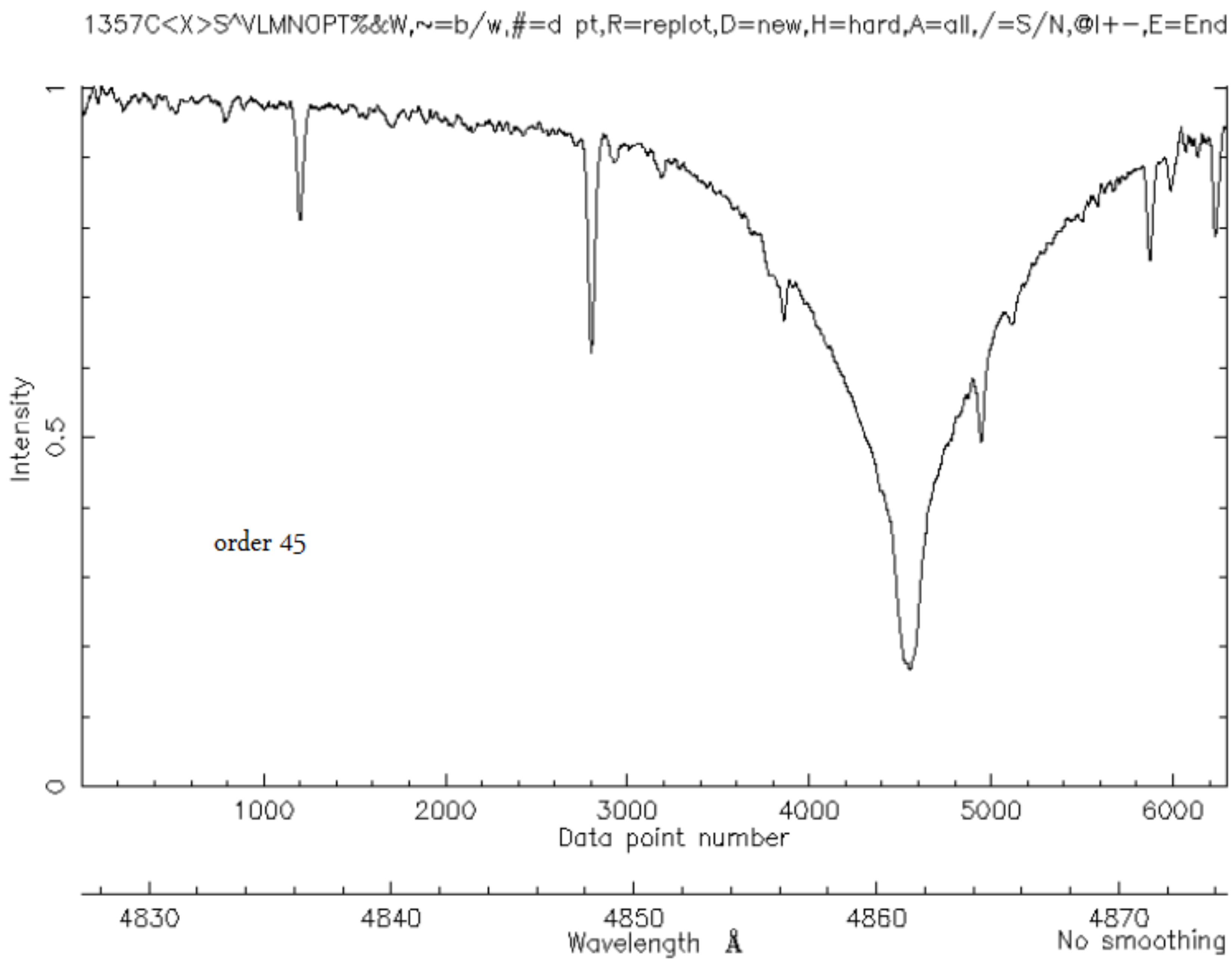
DISCUSSIONS

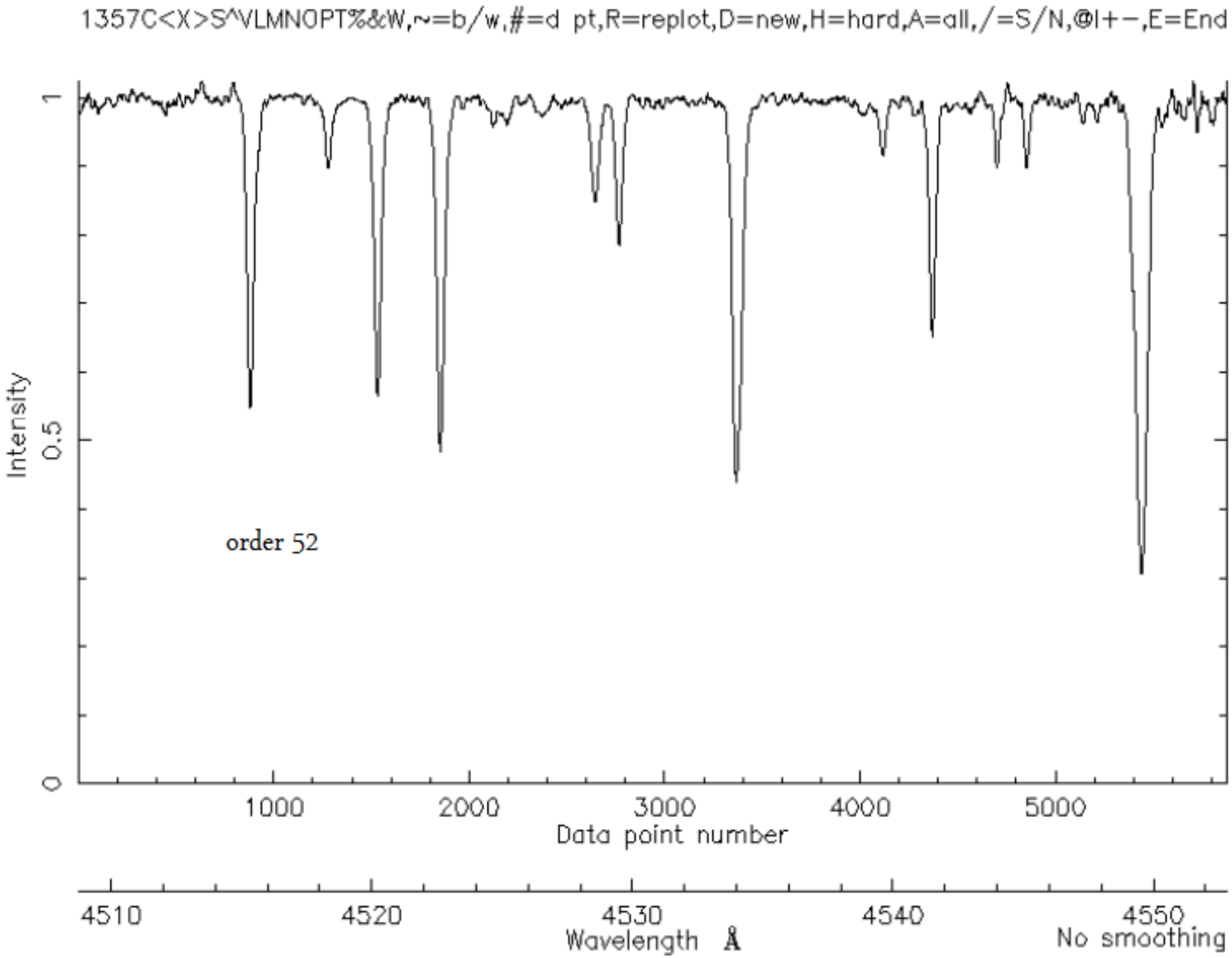
- We experimented our spectra with IRAF reduction techniques.
- The optimal number of bias frames is 20 as beyond 20 the standard deviation of the mean does not increase. As in the reduction procedure the bias is subtracted, the error in the bias is added to the final result.
- In the reduction procedure, the flat field is divided in spectrum after the bias is subtraced, the error in the flat field contributes as a fractional error to the final result
- Coadding spectra increases the final S/N values.

- The edge regions near the **blue** & **red** ends of the order have lower S/N values than the **central** regions. Thus detection of weak lines is best in the center. It is important for especially determine&identify of weak lines of CNO, heavy and rare earth group elements…

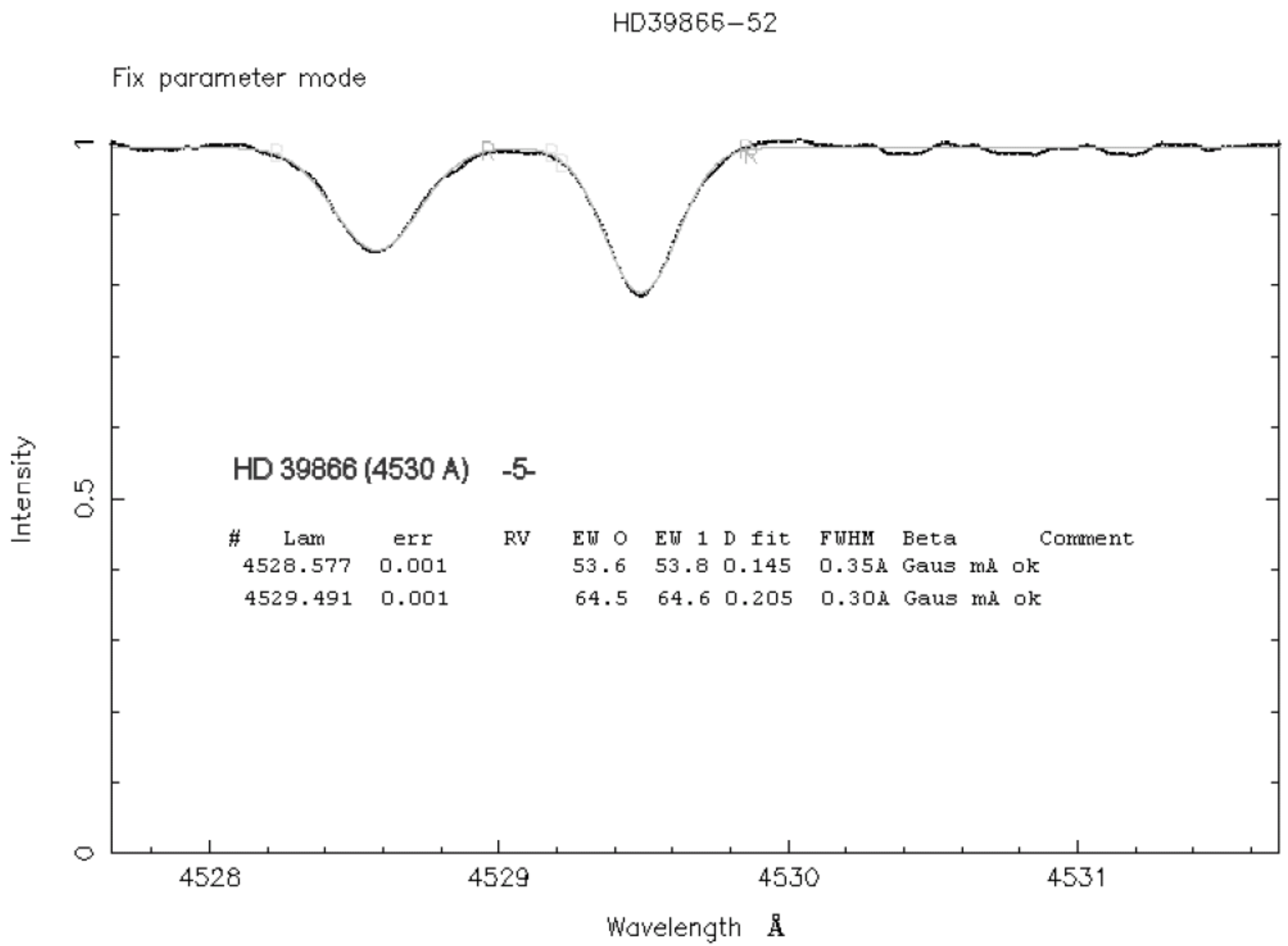
- Comparison is made of certain sections with spectra obtained with the long camera of the DAO coude spectrograph for two supergiants. Analyses show that especially the central parts of the orders permit comparison of CES and DAO equivalent widths. The figures suggests that RTT equivalent widhts are approximately 0.9% larger than their DAO values. S/N is not sufficient for the line profile measurements in especially at the red and blue of the orders. The best orders to measure all spectral lines in an order are between 50 and 55.

- Line profiles are sufficient for spectral analyses with 200+ in the central parts of the orders, but to analyse weaker lines the S/N ratios need to greater than 200 for most of the orders.

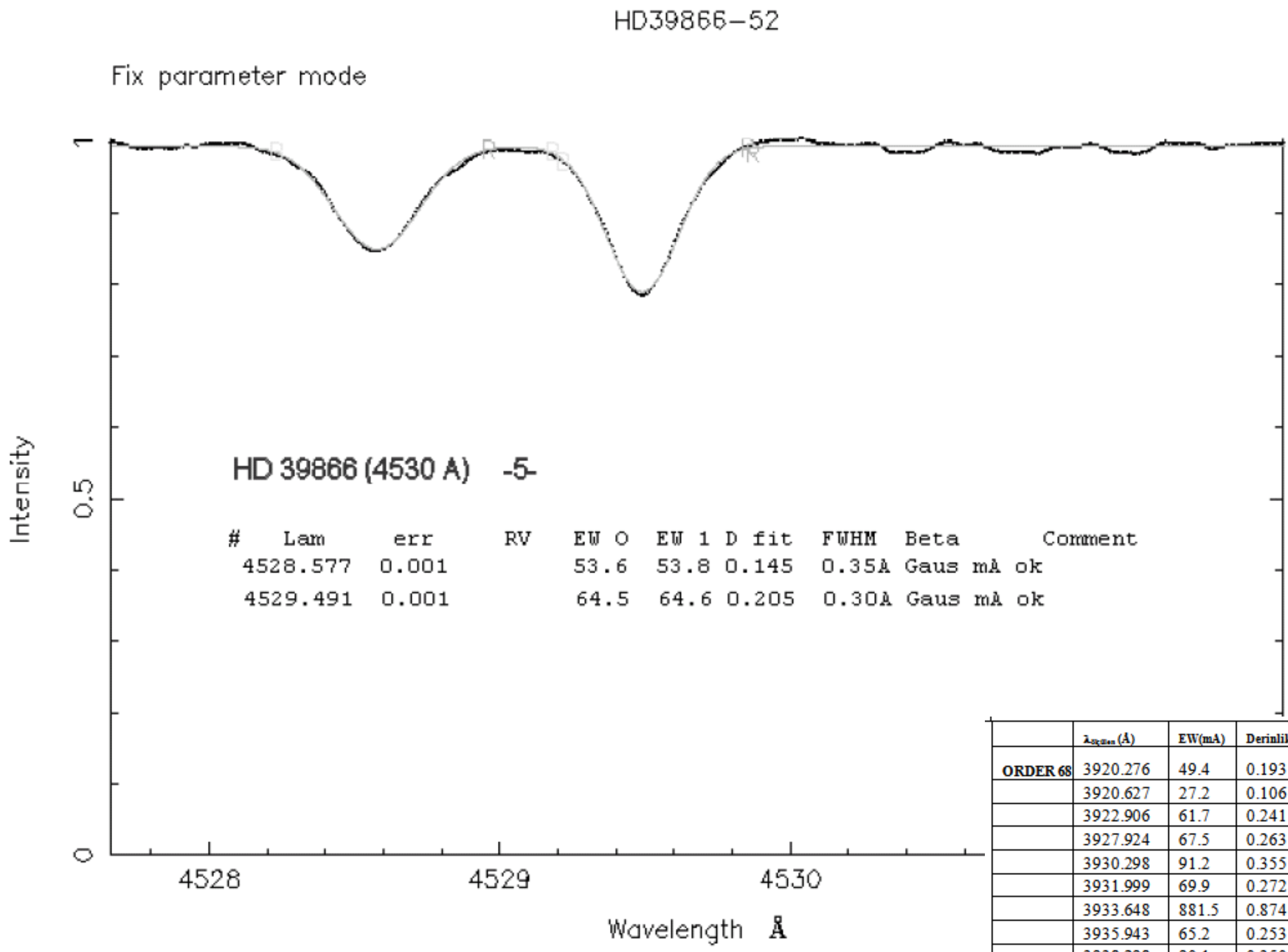

1357C<X>S^VLMNOPT%&W,~=b/w,#=d pt,R=replot,D=new,H=hard,A=all,/=S/N,@I+-,E=End
Intensity
1
0.5
0
1000
2000
3000
4000
5000
6000
Data point number
4830
4840
4850
4860
4870
Wavelength Å
No smoothing
order 45



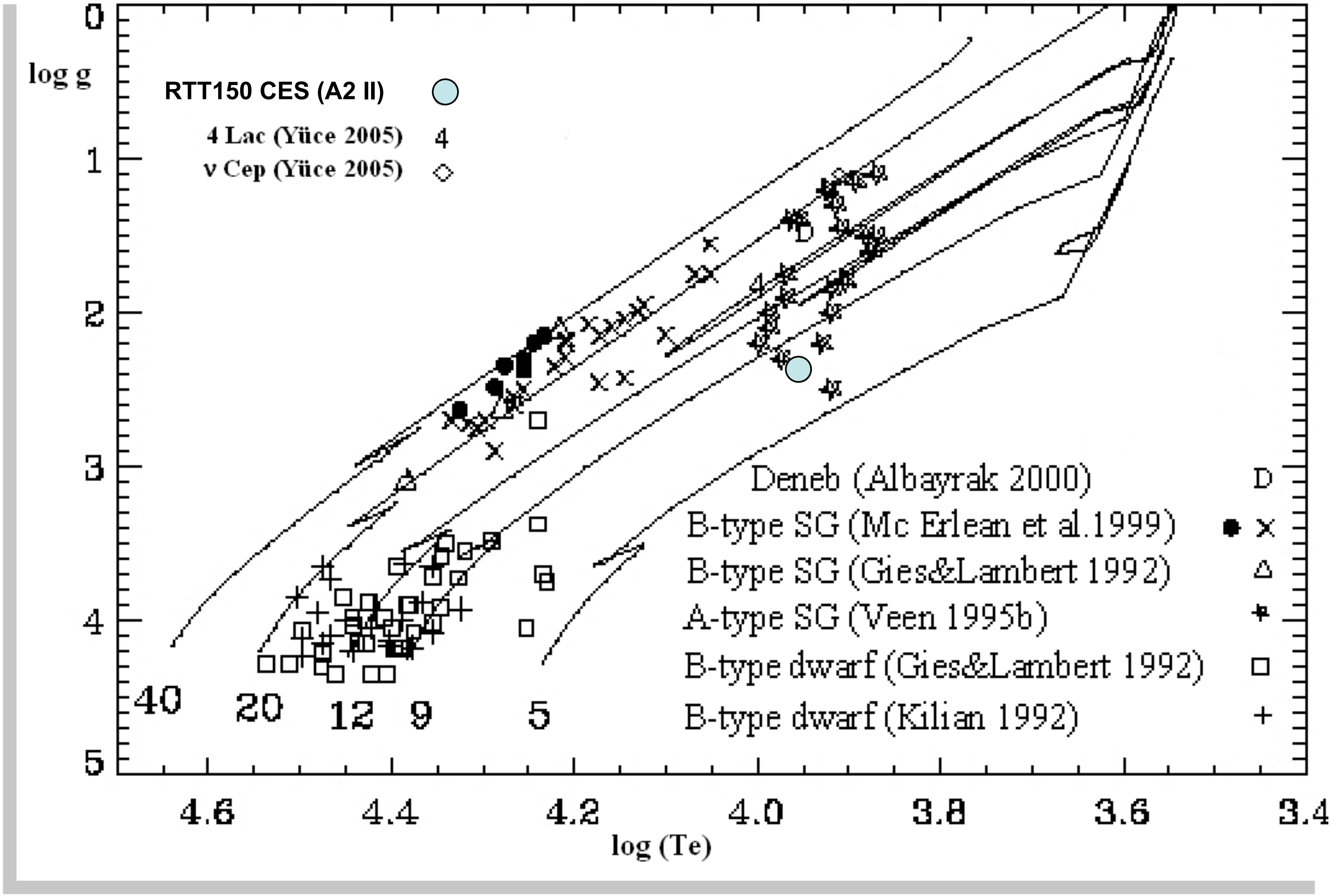
14 April 2010



14 April 2010



	$\lambda_{ölçülen}$ (Å)	EW(mA)	Derinlik	Genişlik		Tanı
ORDER 68	3920.276	49.4	0.193	0.24	f	Fe I (4) 3920.2581 (20r)
	3920.627	27.2	0.106	0.24	f	Fe II (D) 3920.67 (p)
	3922.906	61.7	0.241	0.24	f	Fe I (4) 3922.9118 (25R)
	3927.924	67.5	0.263	0.24	f	Fe I (4) 3927.9199 (30R)
	3930.298	91.2	0.355	0.24	f	Fe I (4) 3930.2967 (25R)
	3931.999	69.9	0.272	0.24	f	Ti II (34) 3932.0087 (120)
	3933.648	881.5	0.874	0.95		Ca II (K) 3933.664 (400R)
	3935.943	65.2	0.253	0.24	f	Fe II (173) 3935.942 (5)
	3938.298	90.1	0.350	0.24	f	Fe II (3) 3938.289 (2)
	3938.961	44.7	0.174	0.24	f	Fe II (190) 3938.969 (4)
	3944.006	73.8	0.286	0.24	f	Al I (1) 3944.009 (10R)
	3945.162	43.6	0.169	0.24	f	Fe II (3) 3945.21 (p)
	3945.334	20.1	0.078	0.24	f	
	3947.482	32.4	0.126	0.24	f	O I (3,3,3) 3947.2948, .481, .4862 (15,14,13)
	3948.970	17.6	0.068	0.24	f	
	3951.984	76.9	0.298	0.24	f	V II (10) 3951.968 (500)
ORDER 67	3951.966	47.6	0.184	0.24	f	V II (10) 3951.968 (500)
	3956.470	24.2	0.094	0.24	f	Fe I (604) 3956.4554 (9)
	3956.722	31.3	0.121	0.24	f	Fe I (278) 3956.6768 (12)
	3958.201	25.0	0.097	0.24	f	Zr II (16) 3958.24 (50)
	3960.877	23.4	0.091	0.24	f	Fe II (212) 3960.895 (3)
	3961.519	85.4	0.330	0.24	f	Al (1) 3961.523 (10R)
	3964.583	30.7	0.118	0.24	f	Fe II (29) 3964.57 (-)
	3966.616	23.1	0.089	0.24	f	(Fe I (282, 562) 3966.630 (10n))



Our detailed spectral analysis results obtained from our individual stars shows that the spectra appeared to be suitable stellar studies especially of their chemical abundances.

The MSc theses supervised by KutluayYüce at the Ankara University.

1. **Tolgahan Kılıçoğlu (completed in 2008)**
"An Elemental Abundance Study of the Low Amplitude δ Scuti Star 20 CVn"

2. **Canan ŞAHİN (completed in 2008)**
"Spectral measurements of HD 43836 (B9 II) using TÜBİTAK National Observatory-Coude Echellé Spectra"

3. **Başak EMİNOĞLU (completed in 2009)**
"Chemical Abundance Analysis of HD 39866 (A2 II) using TÜBİTAK National Observatory-Coude Echellé Spectra"

4. **Sıla ERYILMAZ (started on October 2009)**
"Spectral Reductions and Chemical Abundance Analyses of the Stars 29 And & 89 Cet using TÜBİTAK National Observatory - Coude Echellé spectra"

Thank you…